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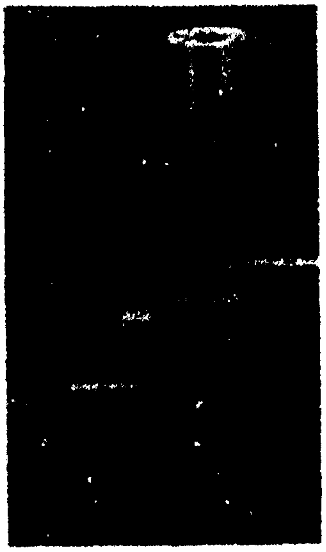

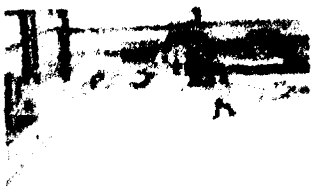

HYDRAULICS LABORATORY

TECHNICAL REPORT HL-91-9

ALTON PUMPING STATION, ALTON, ILLINOIS

Hydraulic Model Investigation

by

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13. ABSTRACT *(Maximum 200 words)*

General (1:10-scale) and section (1:3-scale) models of the approach channel, sump, and pump intakes of the proposed Alton Pumping Station, Alton, IL, were used to evaluate and develop a practical design that would provide satisfactory hydraulic performance for all anticipated flow conditions. The sump included three pumps with a total design capacity of 223 cfs.

Initial operation of the general model with vertical suction intakes indicated substantial swirl in the pump intakes and surface vortices. Various modifications investigated to reduce swirl included elevating the lower edge of the breast wall, closing access ports, streamlining flow by adding a 2.0-ft radius to the lower edge of the breast wall, installing fillets in the corners of the pump bay, and installing a splitter wall beneath the pump bell. A design was developed that provided satisfactory hydraulic performance except when the trashrack was partially blocked.

(Continued)

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13. ABSTRACT (Continued)

A formed suction intake (FSI) was also investigated in the general model. Test results indicated that swirl in the pump intake was satisfactory with the FSI even when the trashrack was partially blocked.

Tests were conducted in a section model primarily to investigate flow distribution in the pump column and to compare hydraulic performance of the vertical suction and formed suction intakes. Flow distribution in the FSI was satisfactory even with 25 percent of the trashrack blocked. The vertical suction and formed suction intakes were similar from a surface vortex standpoint; however, the FSI was superior based on swirl and flow distribution in the pump intake.

PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers (HQUSACE), on 12 October 1984 at the request of the US Army Engineer District, St. Louis. The studies were conducted by personnel of the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES), during the period October 1984 to November 1987 under the direction of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, and R. A. Sager, Assistant Chief of the Hydraulics Laboratory, and under the general supervision of Messrs. G. A. Pickering, Chief of the Hydraulic Structures Division (HSD), Hydraulics Laboratory, and N. R. Oswalt, Chief of the Spillways and Channels Branch (SCB), HSD. Project engineers for the model study were Messrs. T. L. Kirkpatrick and B. P. Fletcher, assisted by Messrs. R. E. Bryant and J. A. Rucker, Jr., all of HSD. The model was constructed by Mr. W. Landers of the Engineering and Construction Services Division, WES. This report was written by Messrs. Kirkpatrick and Fletcher and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

During the model investigation, Messrs. James Luther, Ron Dieckmann, Tim Cronin, and Wayne Miller, St. Louis District, Joe McCormick, Larry Eckenrod, and Larry Cook, US Army Engineer Division, Lower Mississippi Valley, and Bob Kinzel, HQUSACE, visited WES to discuss the program of model tests and observe the model in operation.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres

ALTON PUMPING STATION, ALTON, ILLINOIS

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The proposed Alton Pumping Station will be located in Madison County, Illinois, just south of the city of Alton, IL, and adjacent to the Melvin Price (Lock and Dam 26 (replacement)) project (Figures 1 and 2). The existing flood-control measures in the region consist of several drainage ditches and a pumping station with a pumping capacity of 138 cfs.*

2. A 230-acre ponding area is located to the north of the proposed pumping station (Figure 3). This area will be used to store seepage and storm flows when quantities exceed the capacity of the pumping station and during periods when the area cannot be drained by gravity. A main drainage channel runs through the entire length of the ponding area (Figure 2). The main channel splits about 568 ft upstream of the pumping station to allow separate conveyance of gravity and pumped flows (Figure 3). The drainage channel leading to the pumping station has a 6-ft bottom width and side slopes of 1V on 6H. The capacity of the channel is 263 cfs at a depth of 4.9 ft and a velocity of 2.1 fps. The discharge from the pumping station and the gravity flow channel will be collected in a common discharge chamber. The chamber will permit gravity flow into two existing 60-in. culverts, which pass through the levee and discharge into an existing concrete pad located on the Mississippi River. A steel lining will be placed inside the 60-in. culverts to ensure their structural integrity. The lining will reduce the inside diameter of the culverts to 56 in. and allow a total flow capacity of 250 cfs with no tailwater.

3. The drainage area is an urbanized region with most of the development outside of the floodplain. However, several large industries are located

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

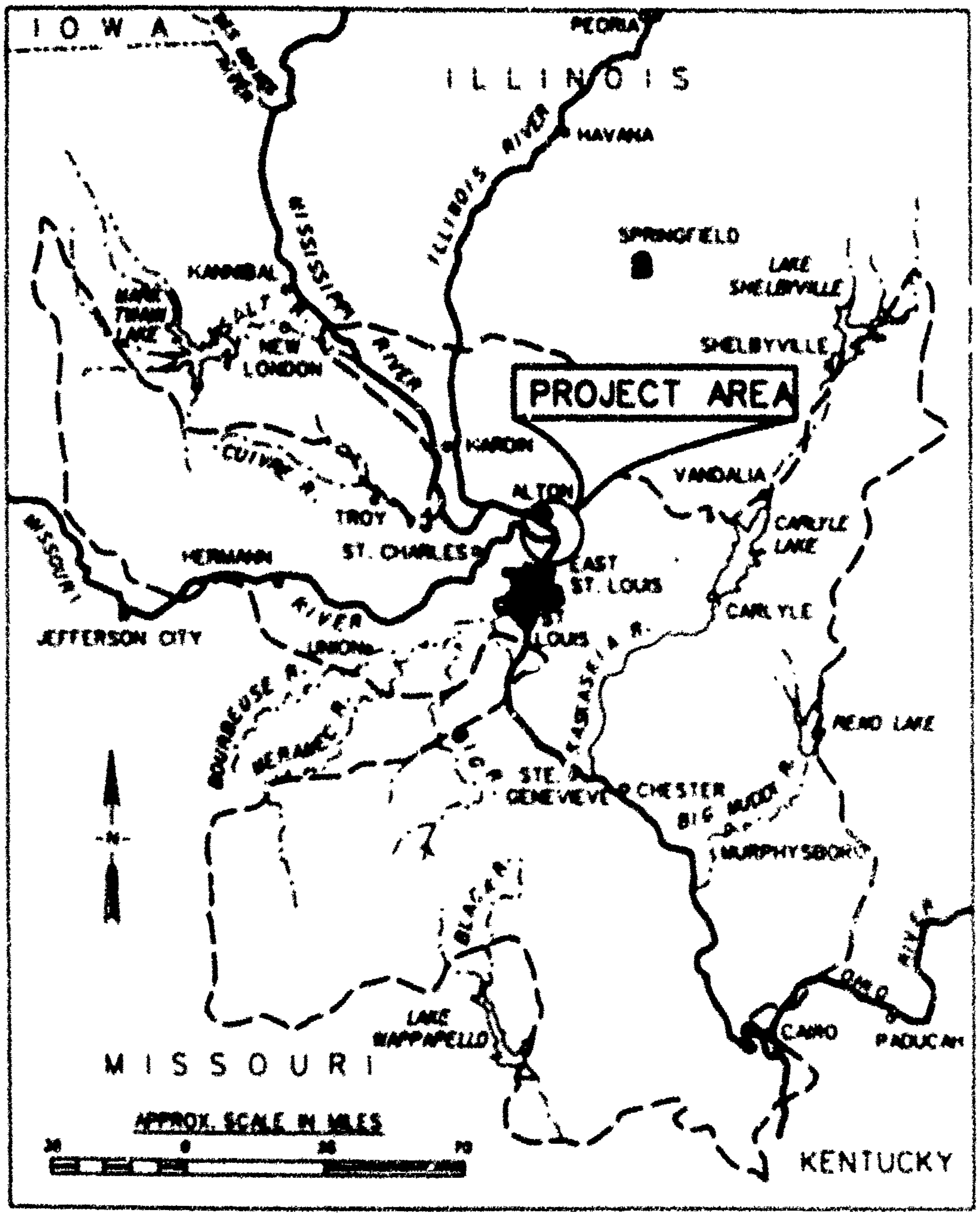

Figure 1 Vicinity map

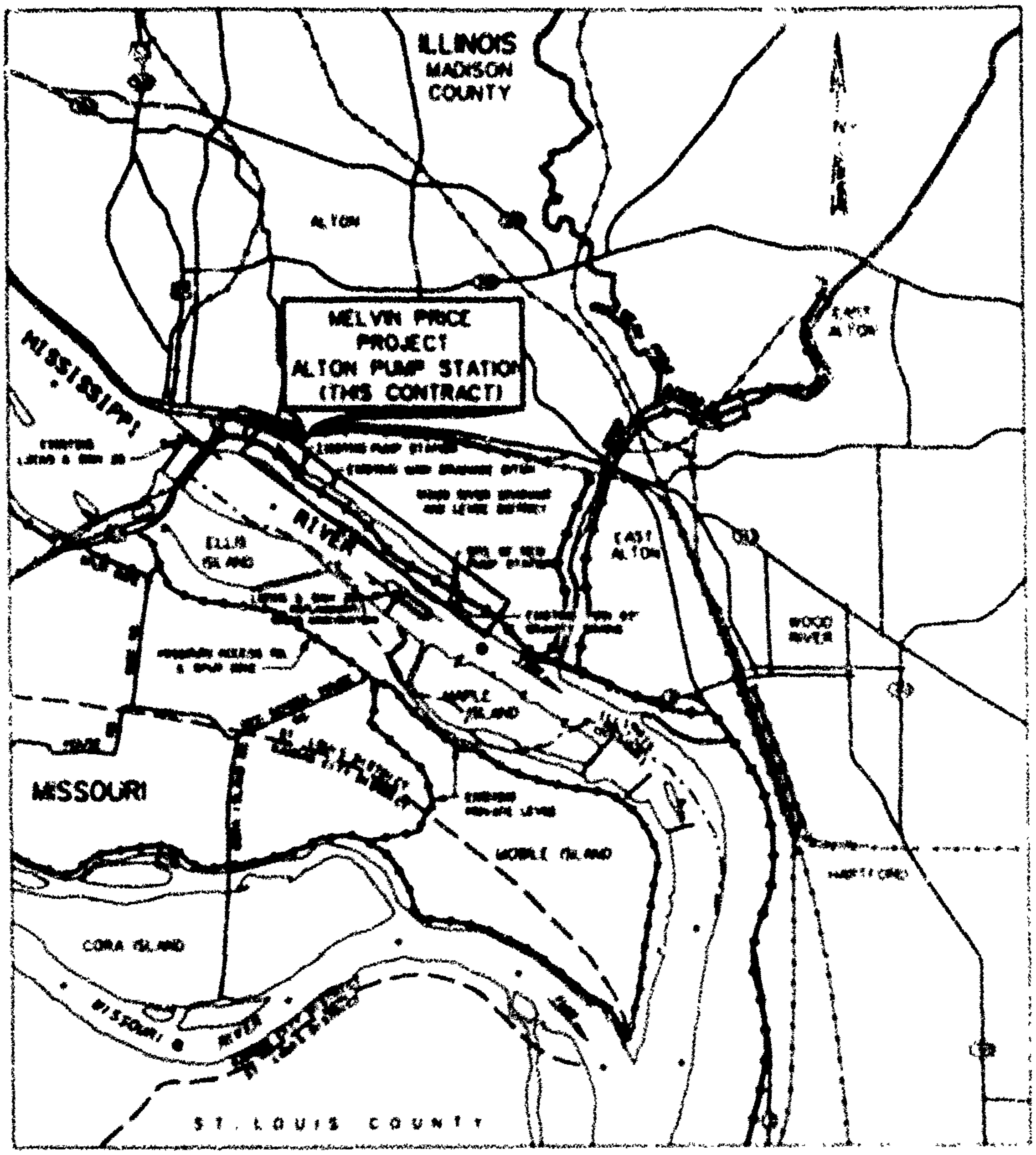

Figure 2   Location map

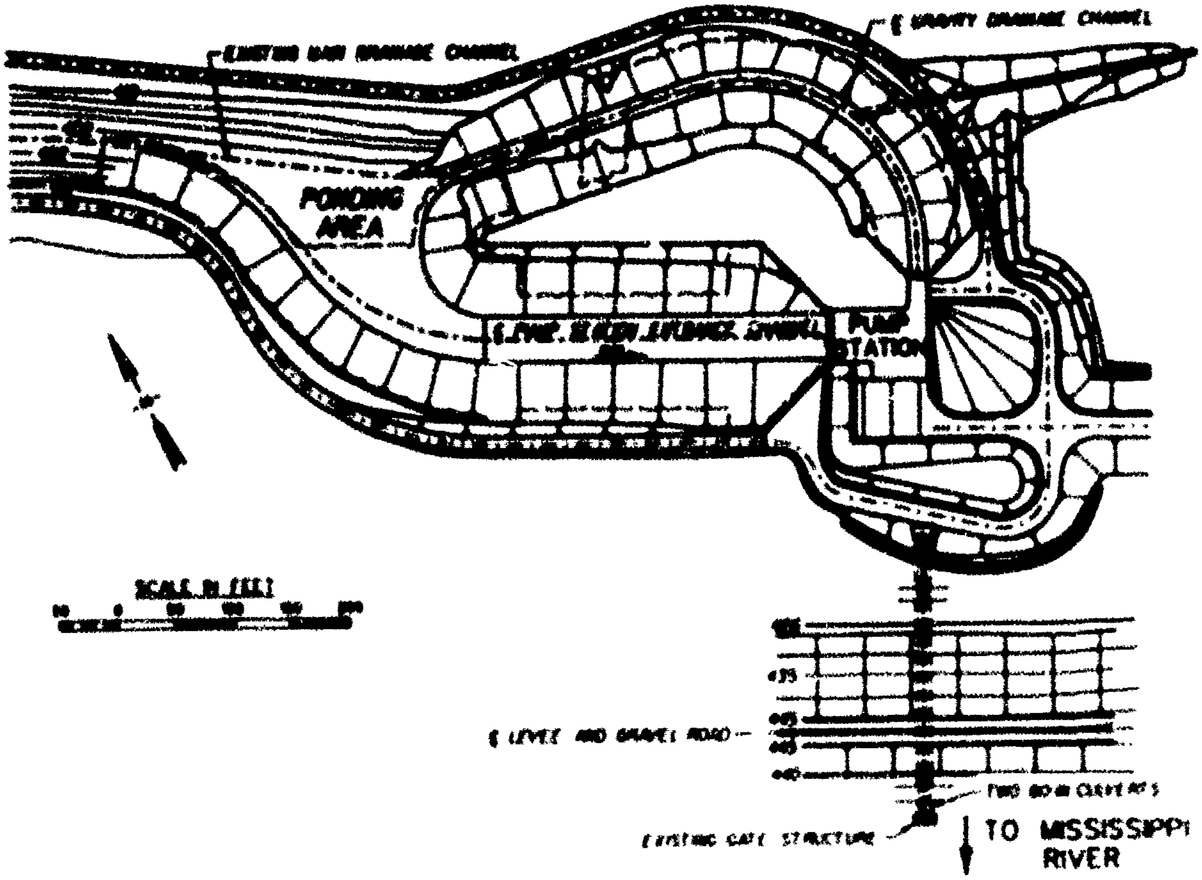

Figure 3 Proposed pumping station

on the outskirts of the floodplain and would suffer extensive damage with a small depth of floodwater. The water-surface elevation in the ponding area varies from 399.5 to 415.8.* Ponding elevations above 415.8 would cause substantial flood damage in the drainage area. The majority of flow entering the drainage area will consist of seepage water from the conservation pool created by the Alton project. The main drainage channel will store flows to a ponding elevation of 410.0. Additional storage is available in the ponding area outside of the drainage channel to a maximum elevation of 413.0, thus allowing a factor of safety to the damage elevation of 415.8. The pumping station is operable to an impoundment elevation of 422.0. The gravity flow channel will be operated to a gate closing impoundment elevation of 404.0. Pumping operations will begin at a minimum impoundment elevation of 406.0.

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

4. The proposed 223-cfs Alton Pumping Station will consist of three individual pump bays and three vertical lift pumps (Plate 1) with a design discharge of 74.4 cfs per pump and a maximum discharge of 112.0 cfs per pump. Each pump bay will be equipped with a mechanically cleaned trashrack to remove any large debris entering the station. A concrete breast wall will be constructed across the width of each bay to provide a support for a closure gate to be used for dewatering purposes. Bulkhead slots are also provided in the bay walls to allow for emergency closure of the pump bay in case of gate failure.

Purpose and Scope of the Model Study

5. Originally, the model study was conducted to evaluate the flow characteristics of the approach channel, pump bays, and vertical pump intake, and to develop modifications that would improve the hydraulic performance of the structure. Additional tests were conducted on a formed suction intake (FSI) design to compare the hydraulic performance of the two designs

PART II: THE MODELS

Description

General model

6. The general model (Figure 4) was constructed to an undistorted linear scale ratio of 1:10. The model reproduced a 400-ft length of the approach channel and the three pump bays and pump intakes. The upstream curved section of the approach channel was molded of pea gravel to sheet metal templates. The downstream trapezoidal section of the approach channel was constructed of marine plywood. The sump and pump intakes were constructed of Plexiglas to permit observation of flow patterns within the sump. Brass rods were used to simulate the trashrack in each pump bay.

7. Individual centrifugal flow pumps were used to recirculate the flow through each pump intake and to permit operation of various pump combinations Digital paddle wheel type flowmeters were used to measure all discharges. Motorized butterfly valves were used to set a given discharge through each pump. An electromagnetic type velocity meter was used to measure all velocities in the model. Confetti and dye were used to observe surface and subsurface flow patterns in the model

Section model

8. The 1:3-scale section model consisted of a single pump bay designed to permit testing of various pump bay and intake designs. The approach channel was not reproduced; therefore, approach flows into the pump bay were not simulated. The section model facility is shown in Plate 2. The pump intake and pump bay side and rear walls were constructed of transparent plastic to permit observation of flow.

9. The method of operation and the equipment (pumps, flowmeters, valves, vortimeters, and velocity meters) used in the section model were essentially the same as described for the general model.

Evaluation Techniques

10. Techniques used for evaluation of hydraulic performance included the following:

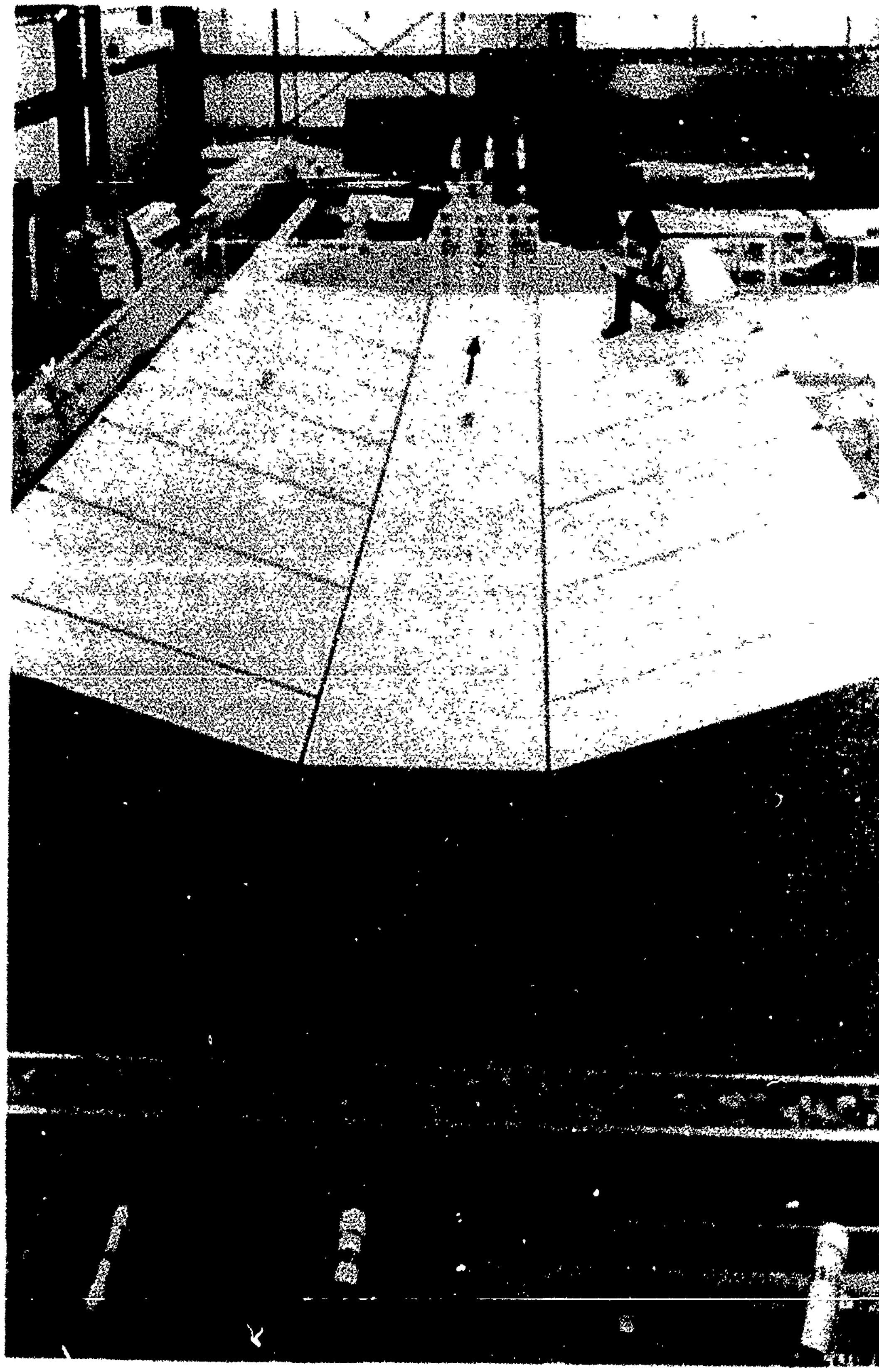


Figure 4   Approach channel

a. Current patterns in the approach channel were determined by means of dye injected into the water and confetti sprinkled on the water surface. Water-surface elevations were measured with staff and point gages. Velocities in the approach channel and pump bays were measured with pitot tubes and electromagnetic velocity probes.

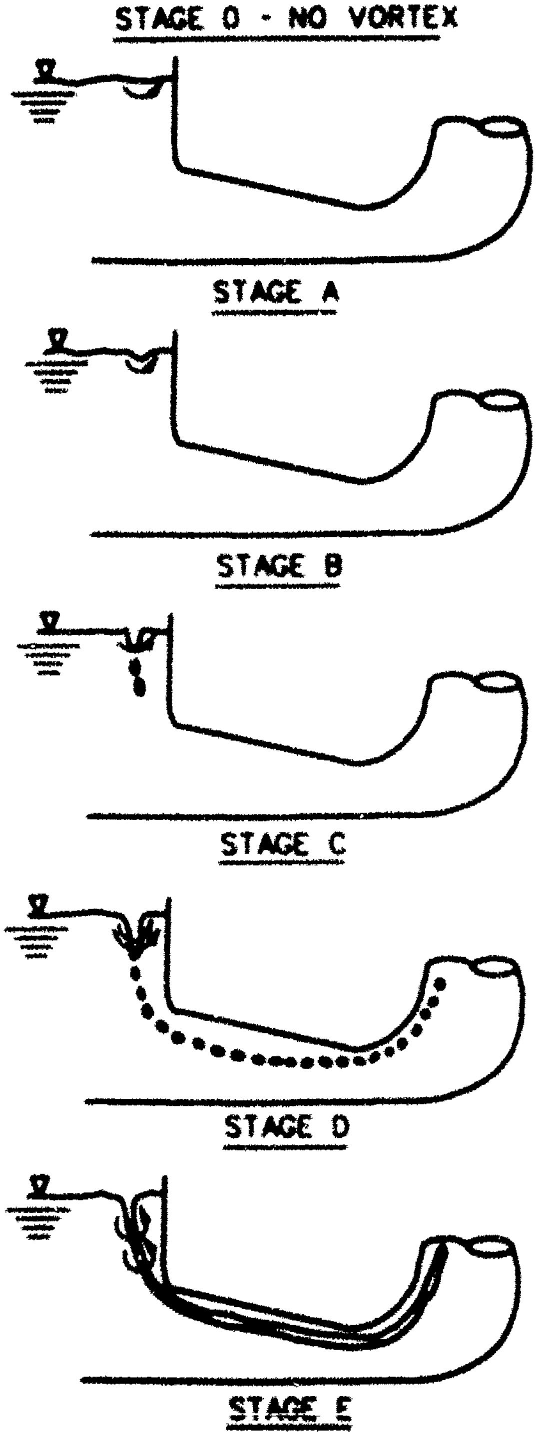


Figure 5. Stages in surface vortex development, FSI

b. Visual observations were made to detect surface and/or submerged vortices. A design that permits a Stage C surface vortex or submerged vortex with a visible air core is considered unacceptable. Stages of surface vortex development are shown in Figure 5. A typical test consisted of documenting, for a given flow condition, the most severe vortex that occurred in a 5-min (model time) period.

c. Swirl angle was measured to indicate the strength of swirl entering the pump intake. A swirl angle that exceeds 3 deg is considered unacceptable. Swirl in the pump columns was indicated by a vortimeter (free-wheeling propeller with zero pitch blades) located inside the pump column (Photo 1). Swirl angle is defined as the ratio of the blade speed V_ϕ at the tip of the vortimeter blade to the average velocity V_a for the cross section of the pump column. The swirl angle ϕ is computed from the following formula.

$$\phi = \tan^{-1} \frac{V_\phi}{V_a} \qquad (1)$$

where

$$V_\phi = \pi dn$$

and

$$V_a = \frac{Q}{A}$$

and

θ = swirl angle, deg

V_θ = tangential velocity at the tip of the vortimeter blade, fps

V_a = average pump column axial velocity, fps

d = pump column diameter (used for blade length), ft

n = revolutions per second of the vortimeter

Q = pump discharge, cfs

A = cross-sectional area of the pump column, ft²

d. Measurement of velocity distribution and flow stability in the pump intake (section model) is discussed in paragraph 22.

Scale Relations

11. The model scales for the general and the section models were computed to provide a Reynolds number greater than 1×10^5, which is the lower limit of turbulent flow as calculated by the following equation

$$R = \frac{VD}{\nu} \qquad (2)$$

where

R = Reynolds number

V = average velocity in pump suction column, fps

D = inside diameter of pump suction column, ft

ν = kinematic viscosity of fluid, ft²/sec

A Reynolds number of this magnitude will ensure that scale effects due to viscous forces will be minimized. The accepted equations of hydraulic similitude, based upon Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the models and prototype. The general relations expressed in terms of the general model and section model scales or length ratios L_r are presented in the following tabulation.

Dimension	Ratio	Scale Relations Model:Prototype General	Section
Length	L_r	1:10	1:3
Area	$A_r = L_r^2$	1:100	1:9
Velocity	$V_r = L_r^{1/2}$	1:3.16	1:1.73
Discharge	$Q_r = L_r^{5/2}$	1:316.23	1:15.60
Time	$T_r = L_r^{1/2}$	1:3.16	1:1.73
Volume	$V_r = L_r^3$	1:1,000	1:27

PART III: TESTS AND RESULTS

General Model

Approach channel

12. The 400-ft-long trapezoidal channel provided an excellent approach geometry as indicated by the surface flow patterns in Photos 2-4. Bottom velocities in the approach are also shown in Plates 3-5. With one or two pumps operating, a slight flow concentration was noted as flow passed around the pier nose of the idle pump bay. Plate 6 shows a plan and profile of the flow patterns in the sump with a single outside pump bay in operation.

Various sump designs (vertical suction intake)

13. In the original (type 1) design sump, the swirl angle increased as the water surface increased to el 415.0. The increase in swirl in the pump intakes was attributed to the strong lateral flow that occurred through the access ports in the interior divider walls. The access ports are 4.0 ft wide and have an invert elevation of 413.0 (Plate 7). The lateral flow through these openings produced flow concentrations that amplified the existing asymmetrical inflow conditions to the pump intakes and created the excessive swirl. Tests conducted with the access ports closed indicated that the access ports should be closed to reduce swirl at water-surface elevations above 413.0. Even with the access ports closed, the reduced swirl was still considered to be excessive and further sump modifications were required.

14. Since flow in the approach channel was fairly evenly distributed, model tests were conducted to determine which components of the pump bay geometry were contributing to the excessive swirl. Three modifications were made to the pump bays during this series of tests. Initially, the breast wall and sidewall contractions (Plate 7) were removed to test flow in an unobstructed pump bay (type 2 design sump). The sidewall contractions were replaced without the breast wall (type 3 design sump). Finally, the breast wall was replaced without the sidewall contractions (type 4 design sump). The following conclusions were drawn from the analysis of these tests.

a. The swirl at the pump intake was practically eliminated with the type 2 design sump (unobstructed pump bay); therefore, the separation of flow around the pier noses (Plate 6) had an insignificant effect on swirl at the pump intakes.

b. The sidewall contractions (Plate 7) produced a small amount of swirl.

c. The breast wall (Plate 7) caused a major portion of the excessive swirl, but removal of the breast wall was not considered a feasible solution since the closure gate (Plate 7) is supported by the breast wall.

15. Several additional sump modifications were tested using various flow stabilizing schemes. None of the modifications yielded satisfactory results for all combinations of pumps operating and water-surface elevations. A 2.0-ft-radius quadrant wall was added to the lower upstream edge of the breast wall to form the type 5 design sump (Plate 8). The quadrant wall reduced the separation of flow from the lower edge of the breast wall and provided a greater flow area with reduced velocities beneath the wall. Vortimeter data indicated this design was ineffective in eliminating the unstable flow and excessive swirl. Fillets were placed in the corners of the pump bay in the type 6 design sump (Plate 9). The purpose of the fillets was to eliminate the stagnant zones in the corners of the pump bay. A significant decrease in the number of vortimeter rotations was noted at a water-surface elevation of 415.0. However, the amount of swirl became excessive with a water-surface elevation of 410.0. A splitter wall placed beneath the pump bell in addition to the corner fillets (type 7 design sump, Plate 10) did not improve the hydraulic performance. The breast wall and sidewall contractions were moved 6.70 ft upstream of their original position in the type 8 design sump (Plate 11). The type 8 design sump provided a greater length of channel downstream of the breast wall for the dissipation of unstable flow conditions. However, this arrangement did not improve the sump performance.

16. Since the removal of the breast wall in the previous model tests had reduced the amount of swirl at the pump intakes, a series of tests were conducted to determine if the breast wall could be raised to a higher elevation to minimize the amount of swirl at the pump intakes. Tests were conducted with the lower edge of the breast wall raised to elevations of 404.0, 405.5, 407.5, 409.5 and 412.0 (type 9-13 design sumps). Test results showed a reduction in swirl for all breast wall elevations of 407.5 or greater (type 11-13 design sumps). A breast wall elevation of 408.0 (type 14 design sump) was recommended, but the US Army Engineer District, St. Louis, expressed concern over structural problems that might be encountered with the breast wall at this elevation. A request was made for tests to evaluate a breast wall at

el 407.0 (type 15 design sump), and these tests indicated satisfactory swirl conditions. The disadvantage of raising the breast wall to a position above the minimum water-surface elevation (el 405.0) is the elimination of the surface turbulence created as flow passes under the wall. The surface turbulence induced is effective in suppressing the formation of surface vortices at the pump intakes (Figure 5). Observations of flows with the type 15 design sump at the minimum water-surface elevation confirmed the presence of Stage D surface vortices (Figure 6). A vortex suppressor beam placed at a strategic

Figure 6. Stage D vortex

location in the pump bay can create enough surface turbulence to eliminate the formation of these vortices. A series of model tests were conducted to determine the proper height and position of the vortex suppressor beam. The majority of the beams tested produced instability in the flow, which caused excessive swirl. These test results indicated that a 0.5-ft-high beam placed

Figure 7. Type 16 design sump

2.4 ft downstream of the pump center line (type 16 design sump, Figure 7) did not contribute to the swirl and prevented surface vortices stronger than Stage A (Figure 5).

17. The type 16 design sump is shown in Plate 12. The following changes were made to the original design sump:

a. The openings in the interior divider walls were closed to prevent lateral flow between adjacent bays.

b. The breast wall was raised to an elevation of 407.0 to reduce the amount of swirl at the pump intakes.

c. A 0.5-ft-high vortex suppressor beam was placed 2.4 ft downstream of the pump center line to prevent the formation of surface vortices. Vortimeter data were recorded at various operating conditions with the type 16 design sump. Comparisons of swirl angles measured with the original (type 1) design sump and the type 16 design sump are shown in Plates 13-15. The comparisons show a large reduction in swirl at all conditions, especially with the higher water-surface

elevations. The type 16 design sump, with no trashrack blockage, provided satisfactory hydraulic performance for all anticipated flow conditions.

Trashrack blockage

18. Subsequent tests were conducted to evaluate the hydraulic performance of the type 16 design sump with trash accumulation over various regions of the trashrack. A dramatic increase in surface vortices (Stage E) and swirl at the pump intakes due to partial blockage (25 percent) of the trashrack was observed. A swirl angle of 31 deg was measured with 25 percent of the trashrack blocked. The blockage extended from the sidewall for a distance of 25 percent of the width and extended from the water surface to the floor of the sump. It was apparent that any significant accumulation of floating or submerged debris on the trashrack would increase the tendency for swirl and surface vortices and adversely affect flow distribution entering the pump intakes.

Various sump designs (FSI)

19. Due to the anticipation of significant trash in the prototype approach channel and its adverse affect on flow entering the pump intakes, tests were conducted with an FSI design (Plate 16). Initially, the FSI was located in pump bay 1 (type 17 design sump) and tested with various combinations of pumps in operation and at various water-surface elevations. The test results showed there was no swirl (0 deg swirl angle) for normal pumping operations. Tests were conducted with trash blockage over various regions of the trashrack. Only minimal swirl (swirl angle less than 1 deg) was detected with trash blockages as large as 75 percent. This was a significant improvement over the type 16 design sump, which was sensitive to trash blockage. Occasional surface vortices (Stage C) were documented without trash blockage. Stage D vortices were observed with the trashrack blocked 25 percent.

Loss coefficients

20. The type 1, 16, and 17 design sumps were simultaneously simulated in the three pump bays as shown in Plate 17. Static pressures were measured in each pump bay using piezometers located in the pump columns and the sump floor (Plate 17). Computations were made for various flow rates and water-surface elevations to determine the effects of the conditions on the values of the head loss coefficient using the following equation

$$k = \frac{H_L}{\left(\frac{V^2}{2g}\right)} \tag{3}$$

where

k = head loss coefficient

H_L = head loss, ft

V = throat velocity, fps

g = acceleration due to gravity, ft/sec^2

Plots of head loss coefficient versus Reynolds number R for various water-surface elevations are presented in Plates 18 and 19. Analysis of these data indicates that the value of the loss coefficient for the FSI design remained constant at about 0.25 $V^2/2g$ for all conditions tested. The loss coefficients for the type 1 and 16 designs ranged from 0.10 to 0.15 $V^2/2g$ lower than the value for the FSI design. These test results indicated that the FSI design provided a much improved flow distribution and less swirl in the pump column at the expense of a slight increase in head loss.

Section Model

21. To further evaluate the Alton sump and pump intake designs by observing vortices and measuring flow distribution in the pump column, a 1:3-scale model was constructed, which simulated a single pump bay and pump intake. The size of the 1:10-scale model was not sufficient to permit measurement of flow distribution in the pump column.

Formed suction intake

22. Tests to document vortex characteristics were initially conducted on the type 17 design sump. The type 17 design sump included an FSI and is shown in Plates 16 and 20. Surface vortices formed in a region just upstream of the FSI, as shown in Plate 20. The results of visual observations are presented in Plate 21, which gives vortex strength as a function of water-surface elevation and discharge. Analysis of these data shows unacceptable vortex formation during anticipated pumping conditions. A Stage C vortex (Figure 5) was considered unacceptable.

23. Two modifications (type 18 and 19 design sumps) to the type 17 design were tested in an attempt to eliminate the unacceptable vortices. The

type 18 design involved placing a wall across the pump bay and around the mouth of the FSI (Plate 22). This modification eliminated circulation behind the pump column and reduced the tendency for surface vortices. Visual observations were made on the type 18 design for va ious water-surface elevations and discharges. Plate 23 shows the results of these observations. The type 18 design reduced the tendency for vortices; however, undesirable vortices occurred under expected pumping conditions for water-surface elevations above 405.0 and discharges above 94 cfs. The unacceptable vortex formation upstream of the type 18 design eliminated this design from any further testing.

24. The type 19 design (Plate 20) involved lowering the upstream closure gate from an initial elevation of 407.0 to a final elevation of 403.0 to attenuate surface vortices. This modification caused the lower portion of the gate to be submerged at all operating conditions. The surface turbulence produced by the submerged gate resulted in a reduction in vortex formation. Lowering the gate upstream of the FSI did not increase the swirl in the pump intake as it did with the vertical suction intake. The results of the visual observations for the type 19 design are given in Plate 24. There were no regions of unsatisfactory hydraulic performance of the type 19 design above the minimum operating water-surface elevation of 405.0 for the range of expected discharge.

25. Velocity patterns measured in the type 19 design are shown in Plate 25. The head loss caused by the breast wall is also shown in Plate 25.

26. The type 17, 18, and 19 designs were tested with a 25 percent blockage of the trashrack under the same conditions as all previous tests. The blockage extended from the sidewall for a distance of 25 percent of the bay width and extended from the water surface to the floor of the sump. Flow concentrations were produced by the blockage, which increased vortex formation. The results of the model tests are presented in Plates 26-28. Unacceptable vortex formations occurred under normal pumping conditions for all FSI designs with 25 percent of the trashrack blocked.

27. A data collection system was set up to evaluate the velocity distribution in the pump column of the type 19 design at the approximate location of the pump impeller. A profile and cross section of the type 19 design is shown in Plate 29. The lower edge of the pump impeller would be located at the 24-in. constriction of the pump column (Section A-A). Copper

tubes (1/8-in. ID) were installed with their tips at Section A-A to measure the total pressure at 25 various points in the pump column as shown in Plate 29 and Photo 1. Four piezometers were located around the periphery of the pump column (Plate 29) to measure the average static pressure at this location. The four piezometers were placed above the plane of the impact tubes (Plate 29) to reduce the effects of the localized low-pressure zone caused by the constriction in the pump column. An adjustment factor was established to correct for the differences in head loss, velocity head, and elevation between the impact tubes and piezometers. The head differential was measured using 25 individual electronic differential pressure cells. The cells were connected to a computerized data acquisition system capable of collecting data for chosen lengths of time and sampling at various rates. A velocity was computed from the measured head differential and then normalized by dividing the measured velocity by the theoretical average velocity of the cross section. A deviation of 10 percent or greater in the ratio of the average measured velocity at a point to the average computed velocity in the cross section was considered unacceptable. A sampling rate of 100 samples per second was used during a test period of 60 sec for all model tests.

28. Velocity ratio contour plots were made for model tests conducted with the type 17 and 19 designs and are presented in Plates 30 and 31, respectively. The contour lines on these plots represent equal average velocity ratios. The plots were made using average velocity ratios, since this is the criterion used to determine acceptable hydraulic performance. A contour plot for the type 19 design intakes with 25 percent trashrack blockage is shown in Plate 32. These results do not indicate any significant change in the velocity distributions due to the trash blockage. The contour plots in Plates 30-32 show the average velocity ratio to be within 10 percent of unity, which is considered to be acceptable.

29. Type 17 and 18 designs were unsatisfactory with or without trashrack blockage due to the presence of surface vortices in the pump bay. The type 19 design provided satisfactory hydraulic performance for all anticipated flow conditions, provided surface vortices are not generated by a partially blocked trashrack.

<u>Vertical suction intake</u>

30. Tests were conducted in a 1:3-scale model of the type 16 design sump to document stages of surface vortex development and flow distribution in

the pump intake and to enable a comparison of hydraulic performance between a vertical suction intake (type 16 design sump, Plate 12) and an FSI (type 19 design sump, Plate 16).

31. The results of vortex observations are presented in Plate 33, which shows surface vortex stage as a function of water-surface elevation. Plate 33 indicates satisfactory performance (no Stage C vortices) for water-surface elevations as low as the minimum anticipated.

32. The type 16 design was tested with 25 percent blockage of the trashrack. The blockage extended from the sidewall for a distance of 25 percent of the bay width and extended from the water surface to the floor of the sump. The blockage concentrated the approach flow, which increased the circulation in the pump bay and the strength (stage) of the vortex formations (Plate 34).

33. Results of tests to define flow distribution in the type 16 design with and without trashrack blockage are presented as contour lines of equal velocity ratios in Plates 35 and 36, respectively. A comparison of Plates 31 and 32 with Plates 35 and 36 indicates that the flow is better distributed in the pump column with the FSI.

Recommended Design

34. Test results from the general and section models indicate that from a surface vortex standpoint, the type 16 design (suction bell intake) is equivalent to the type 19 design (FSI). However, from the standpoint of swirl and flow distribution in the pump intake, with and without trash blockage, the type 19 was superior. Based on hydraulic performance documented from the model tests, the type 19 design (Plates 16 and 20) was recommended for the Alton Pumping Station.

PART IV: DISCUSSION AND CONCLUSIONS

35. In the general model, the 400-ft-long trapezoidal approach channel provided satisfactory flow distribution to the sump. Initial tests indicated that the access ports in the interior divider walls should be closed to reduce the swirl angle of flow entering the pump intakes. Even with the access ports closed, the reduced swirl was considered to be excessive.

36. Modifications to reduce swirl included removing breast wall and sidewall contractions, streamlining flow by adding a 2.0-ft-radius quadrant wall to the lower edge of the breast wall, locating fillets in the corners of the pump bay, and locating a splitter wall beneath the pump bell. Removal of the breast wall did significantly reduce the swirl to an acceptable degree. However, removal of the breast wall was not considered a feasible solution since the closure gate is supported by the breast wall. Tests were conducted to determine if the breast wall could be raised to a higher elevation to minimize the amount of swirl at the pump intakes. Satisfactory hydraulic performance relative to swirl was obtained with the breast wall raised 4.0 ft to el 407.0. However, raising the breast wall above the minimum sump elevation of 405.0 eliminated the surface turbulence generated by the breast wall, which was effective in suppressing the formation of surface vortices. The tendency for surface vortices was reduced to an acceptable level by installing a vortex suppressor beam in each pump bay (type 16 design).

37. When the type 16 design was subjected to partial trashrack blockage, a dramatic increase in surface vortices and swirl in the pump intake was observed.

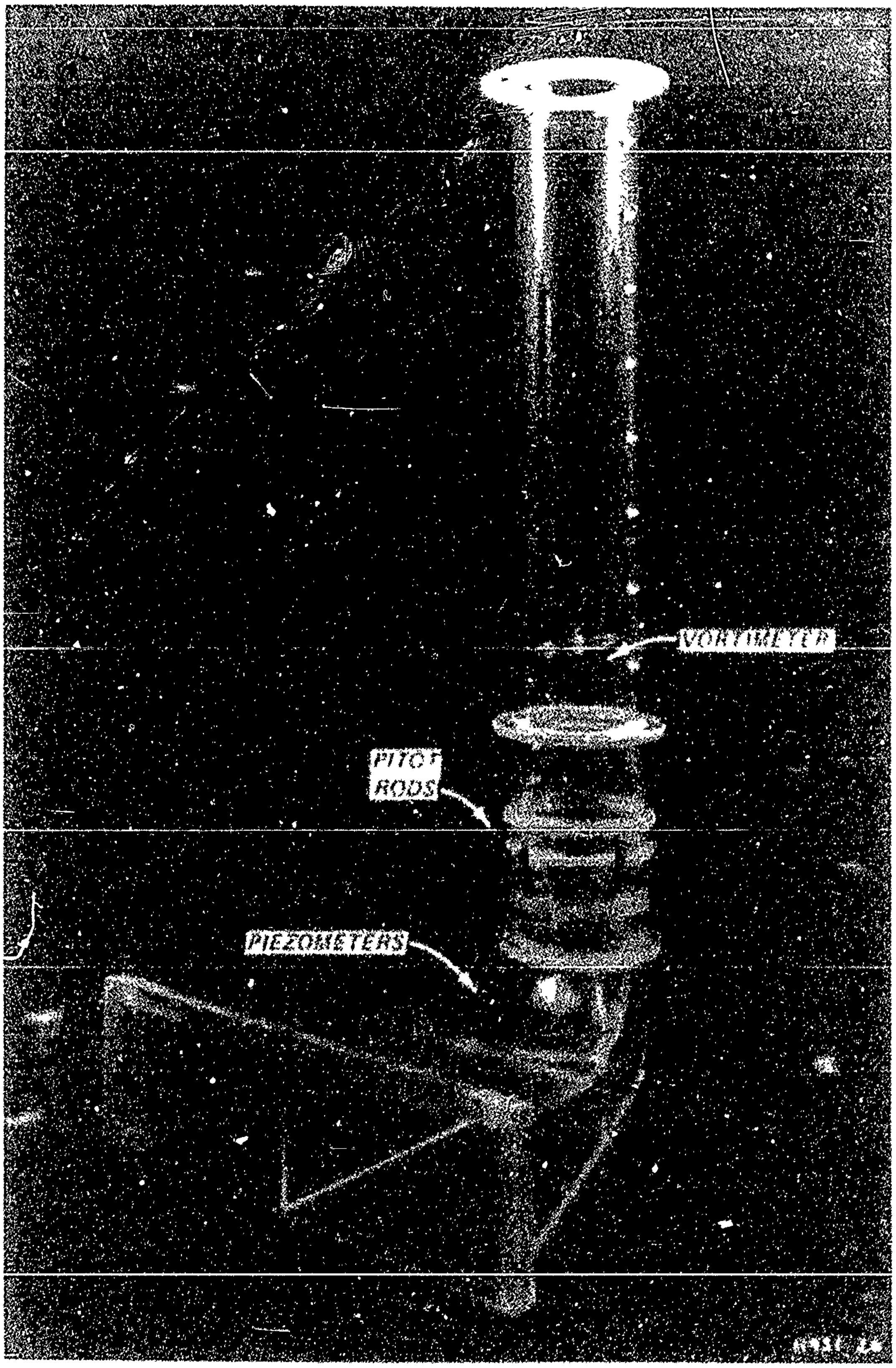
38. To alleviate the adverse hydraulic conditions caused by trashrack blockage, a formed suction intake (FSI) was investigated. Only minimal swirl was detected with trashrack blockage as large as 75 percent. Undesirable surface vortices were observed with the trashrack blocked 25 percent.

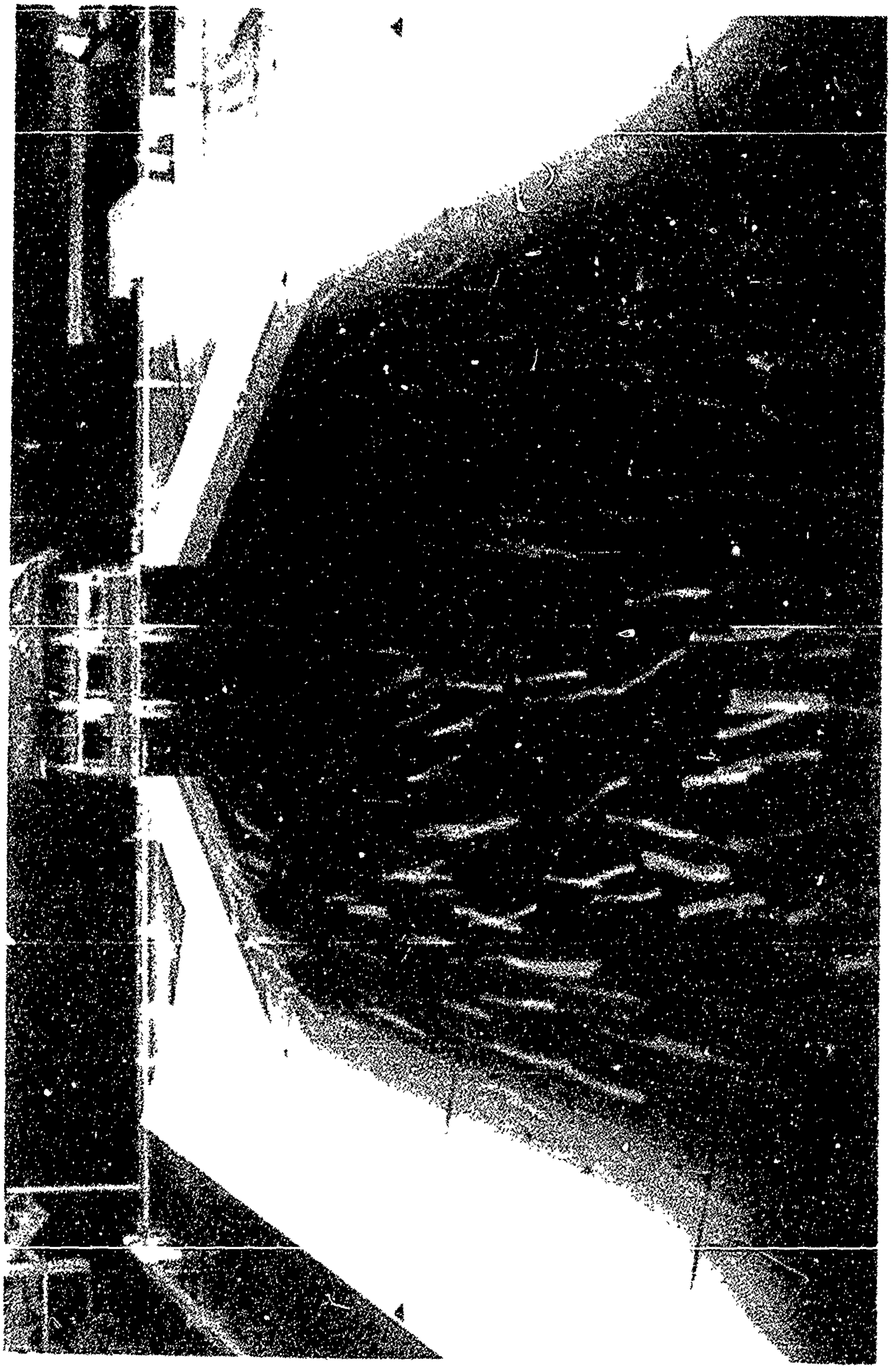
39. Tests conducted to compare the head loss through the vertical and formed suction intakes indicated that the loss coefficients ranged from 0.10 to 0.15 $V_t/2g$ higher in the FSI. The FSI provided a much improved flow distribution and less swirl at the expense of a slight increase in head loss.

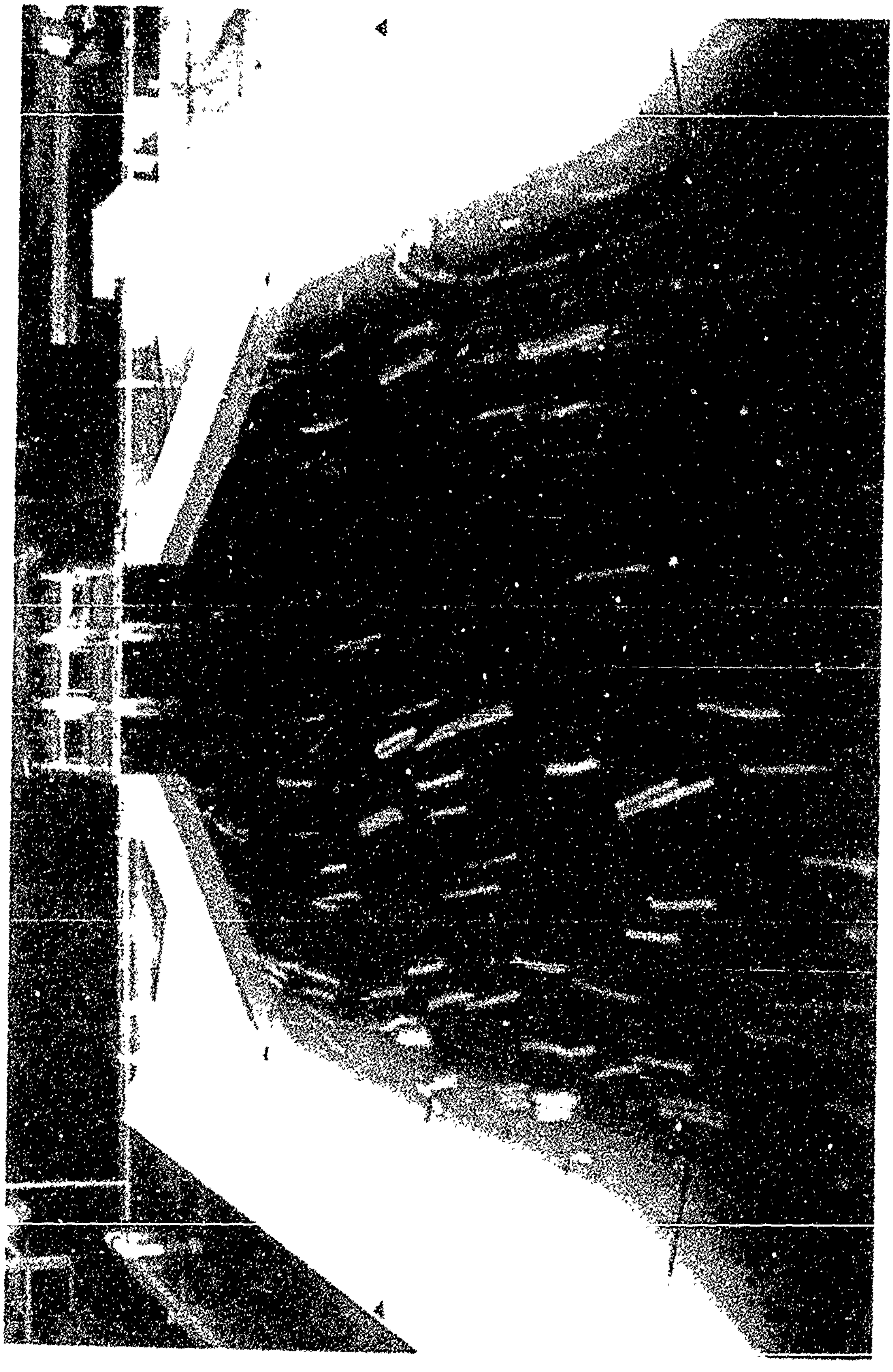
40. Tests were conducted in a section model (one pump bay) primarily to investigate flow distribution in the pump column. The general model was not designed for measurement of flow distribution in the pump column. Test

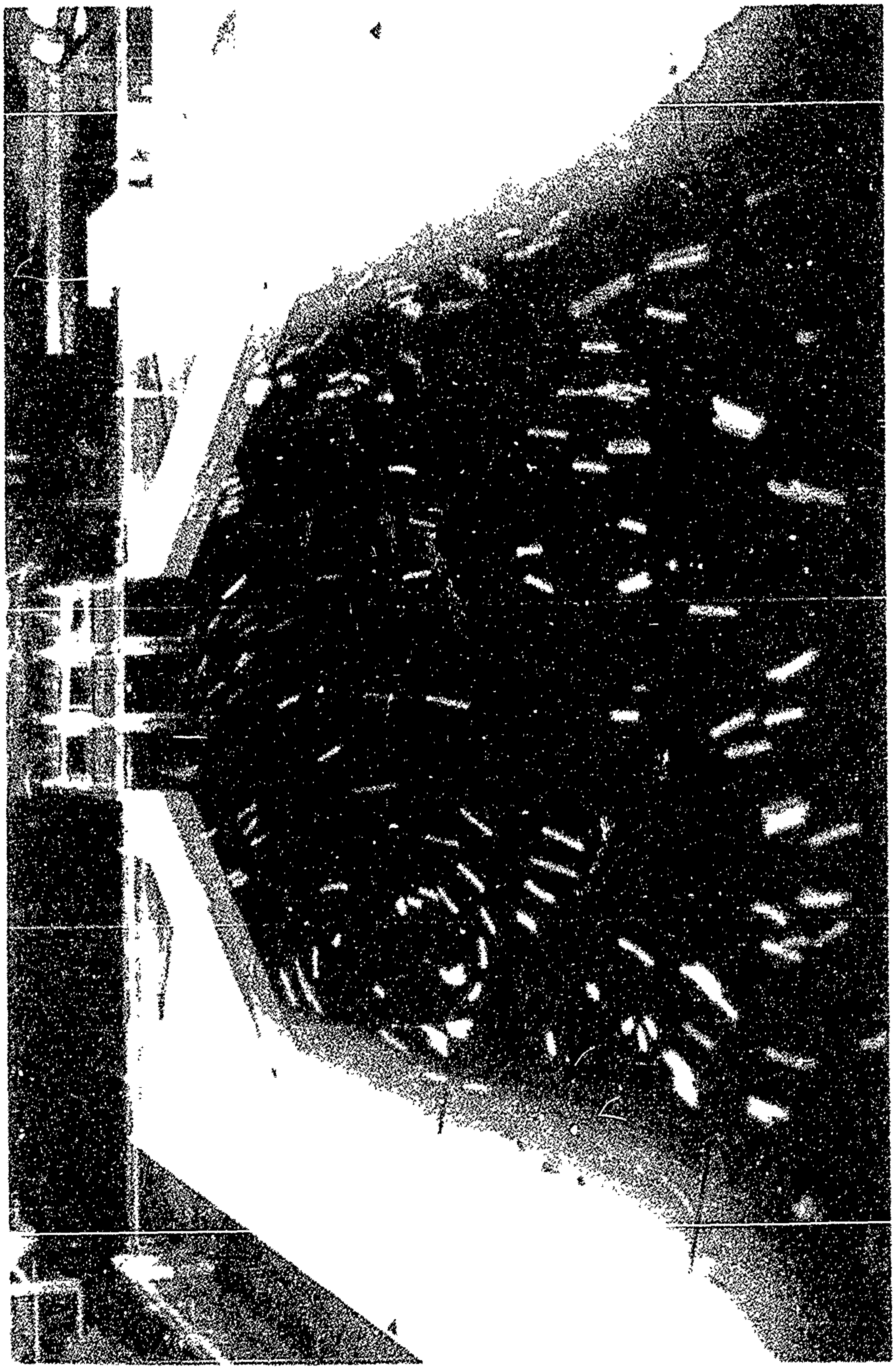
results indicated that the type 19 FSI provided satisfactory flow distribution with any anticipated flow condition, even with 25 percent of the trashrack blocked.

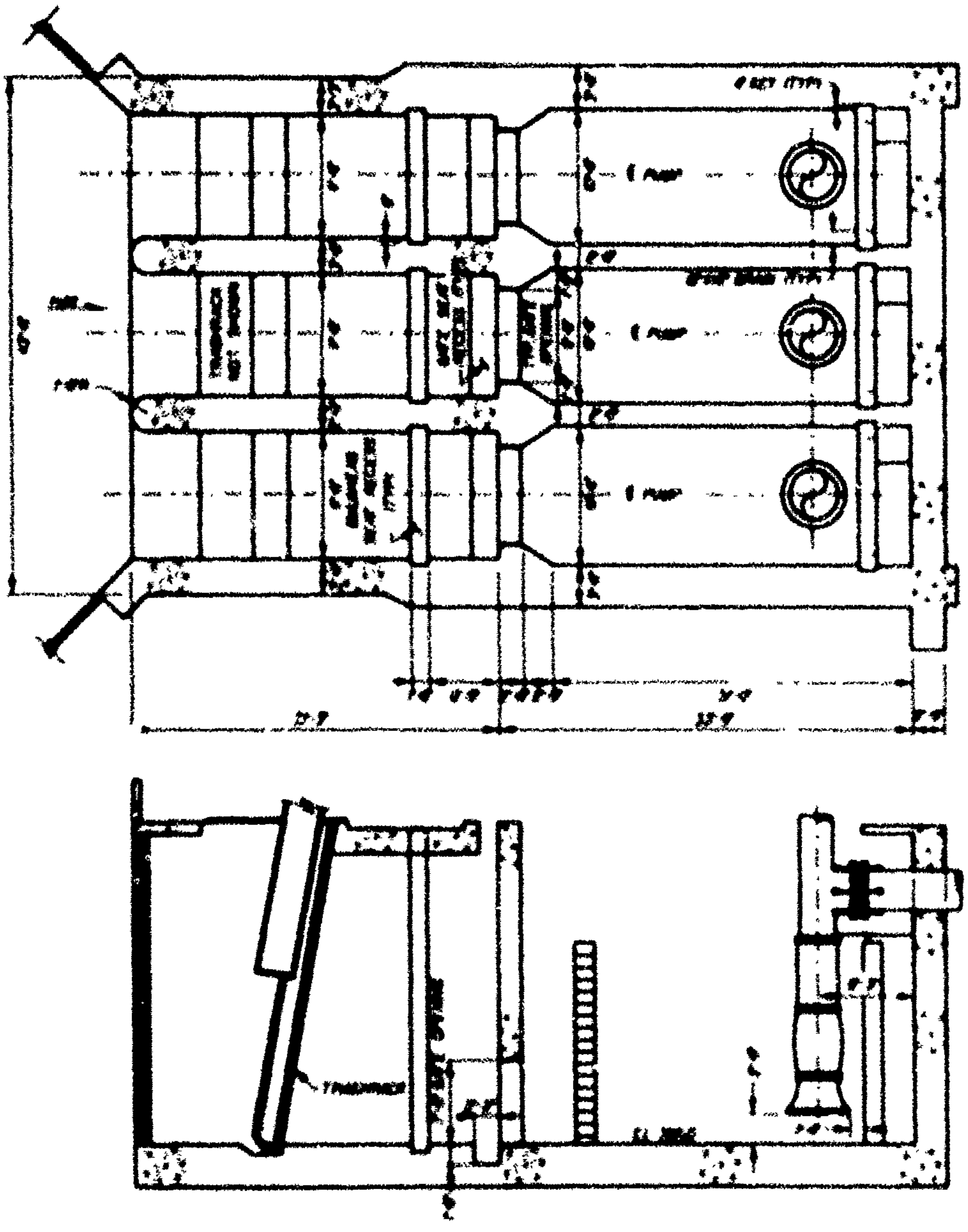
41. Additional tests were conducted in the section model to evalu te flow conditions with a vertical suction intake (type 16 design) and to compare hydraulic performance obtained with the FSI (type 19 design). Test results from the general and section models indicate that the type 16 and 19 designs were similar from a surface vortex standpoint. From the standpoint of swirl and flow distribution in the pump intake, the type 19 design was superior Based on test results, the type 19 design was recommended.


VORTIMETER
PITOT RODS
PIEZOMETERS

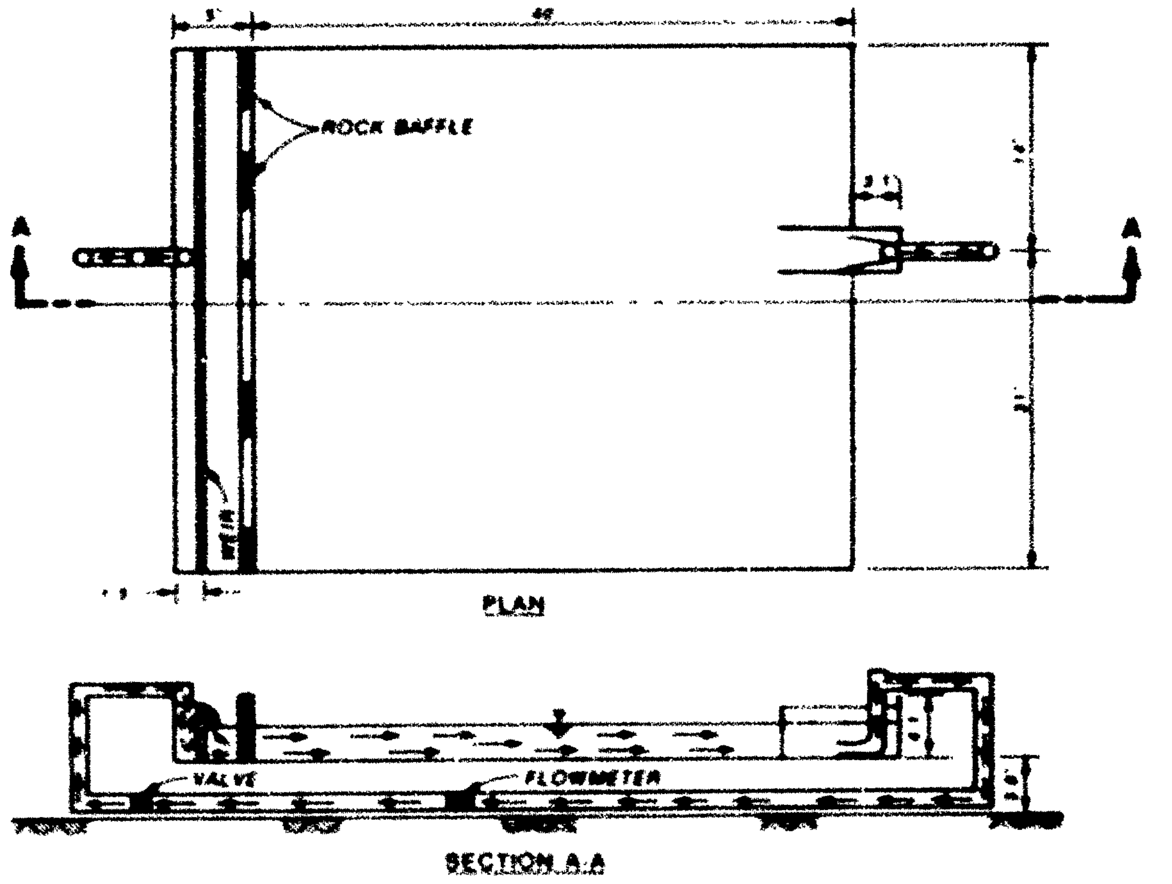






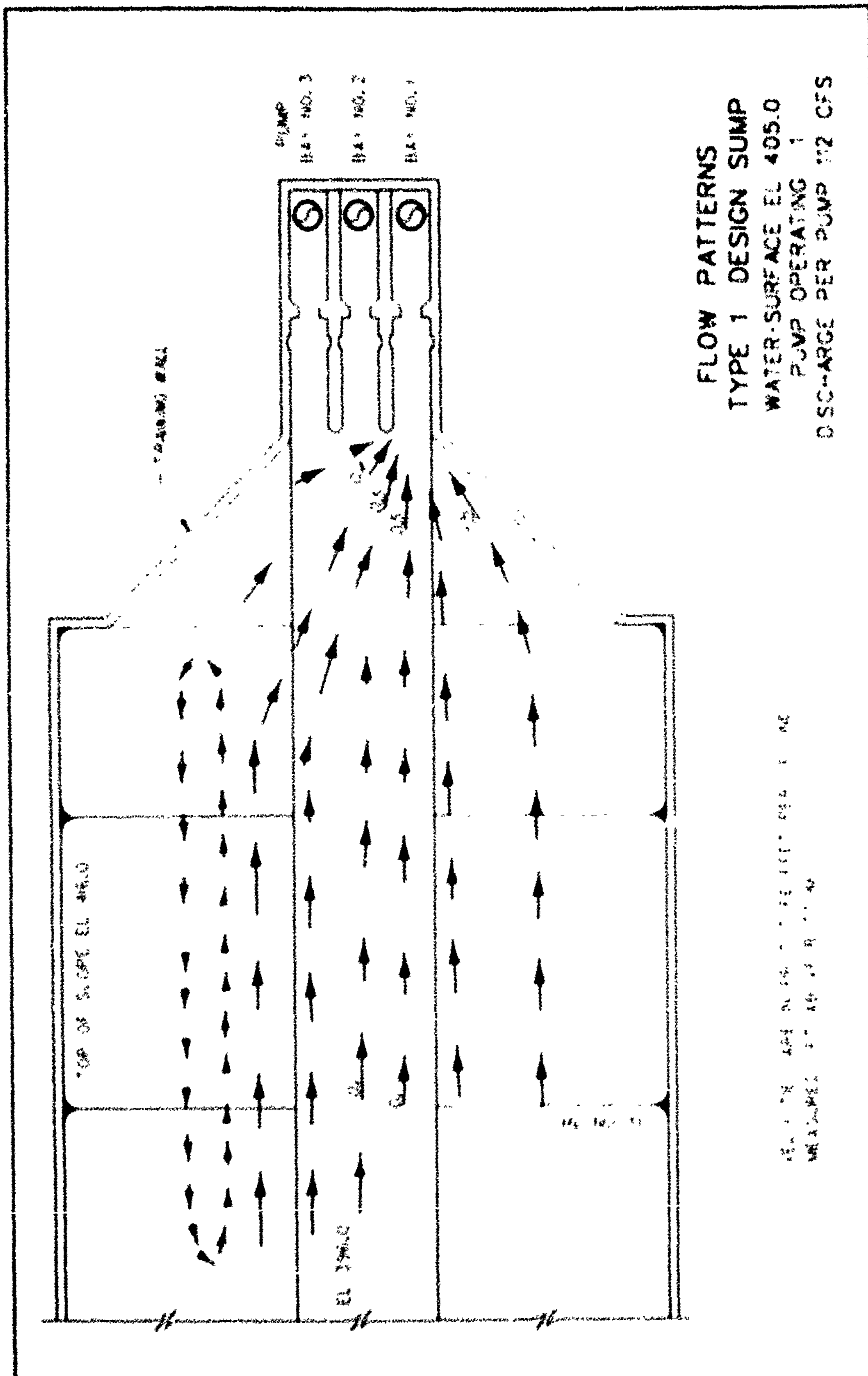


TYPE 1
(ORIGINAL DESIGN)
PUMPING STATION

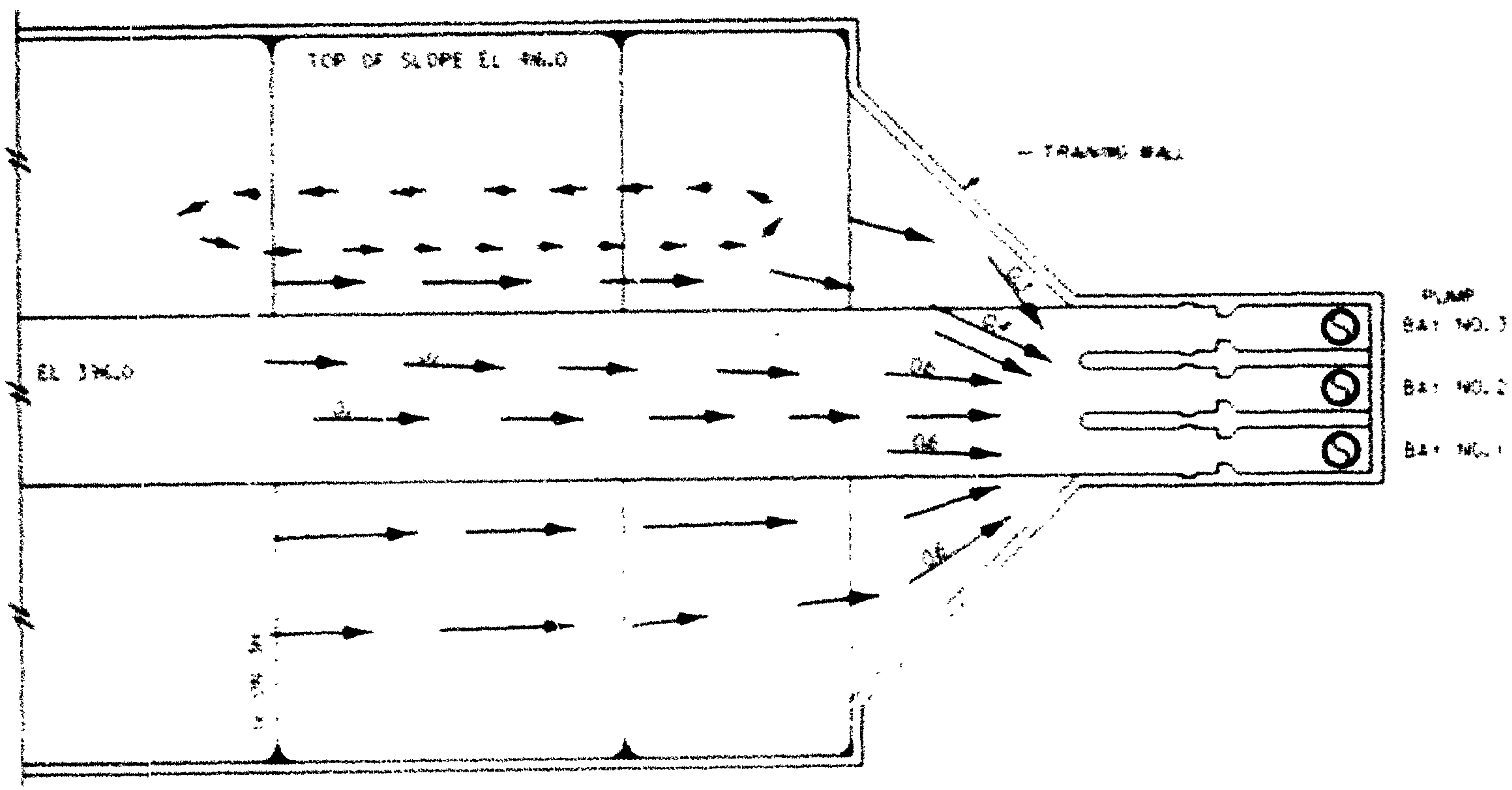


SECTION MODEL

PLATE 2

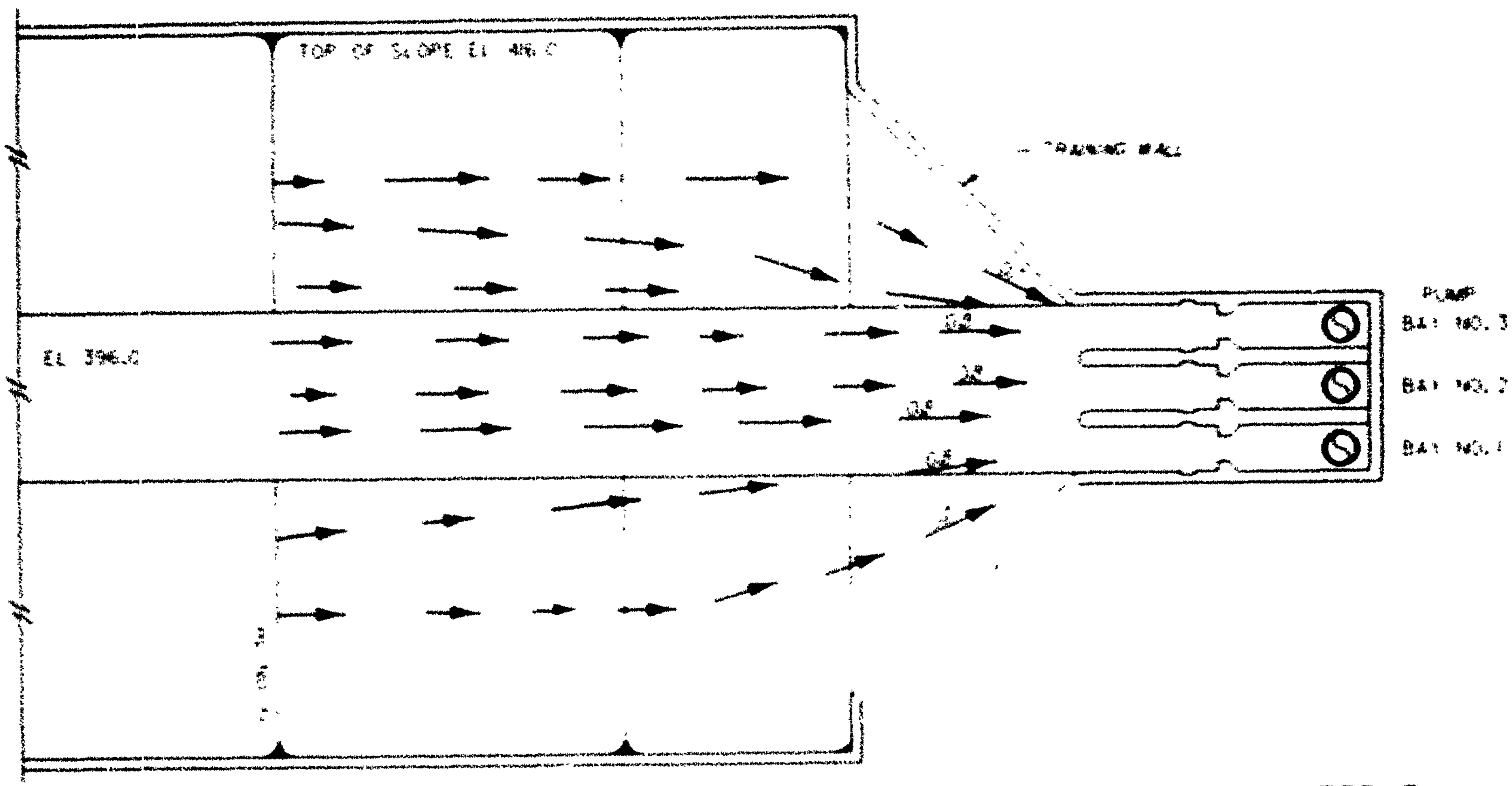


FLOW PATTERNS
TYPE 1 DESIGN SUMP
WATER-SURFACE EL 405.0
PUMP OPERATING 1
DISCHARGE PER PUMP 112 CFS

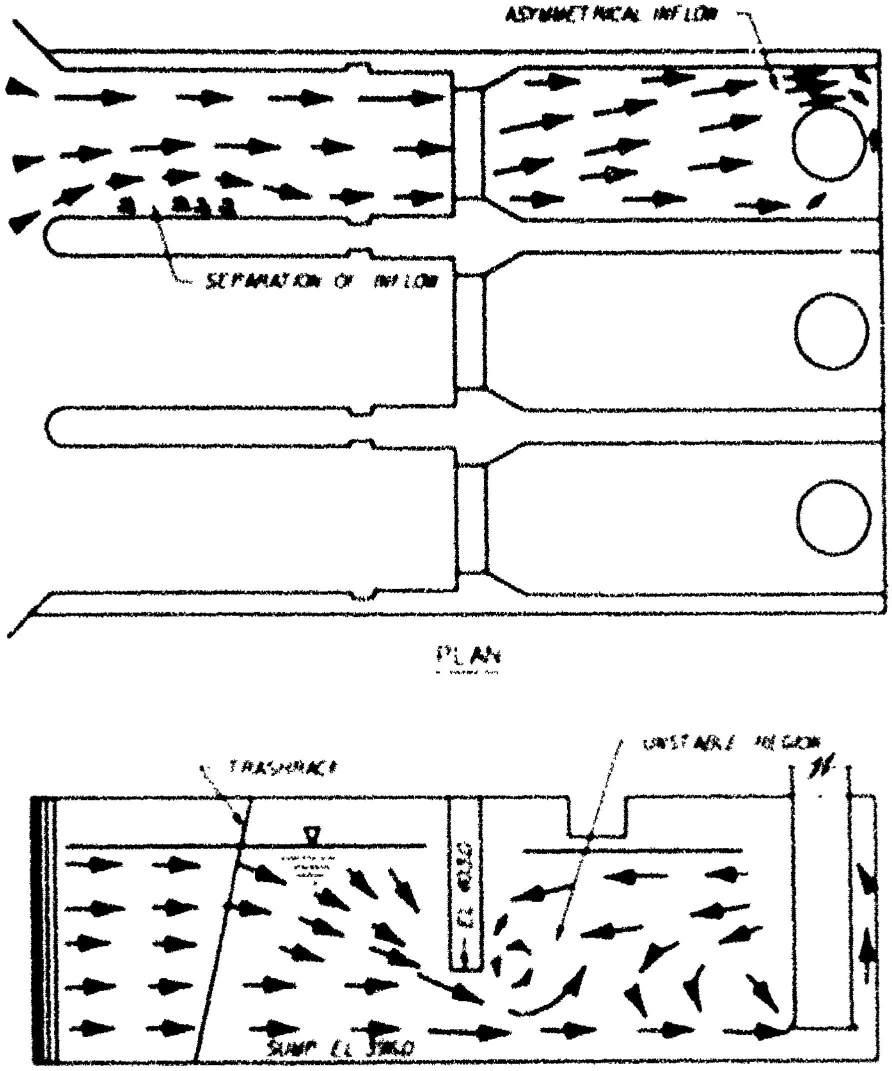


FLOW PATTERNS
TYPE 1 DESIGN SUMP
WATER-SURFACE EL 405.0
PUMPS OPERATING 1, 2
DISCHARGE PER PUMP 112 CFS

PLATE 4

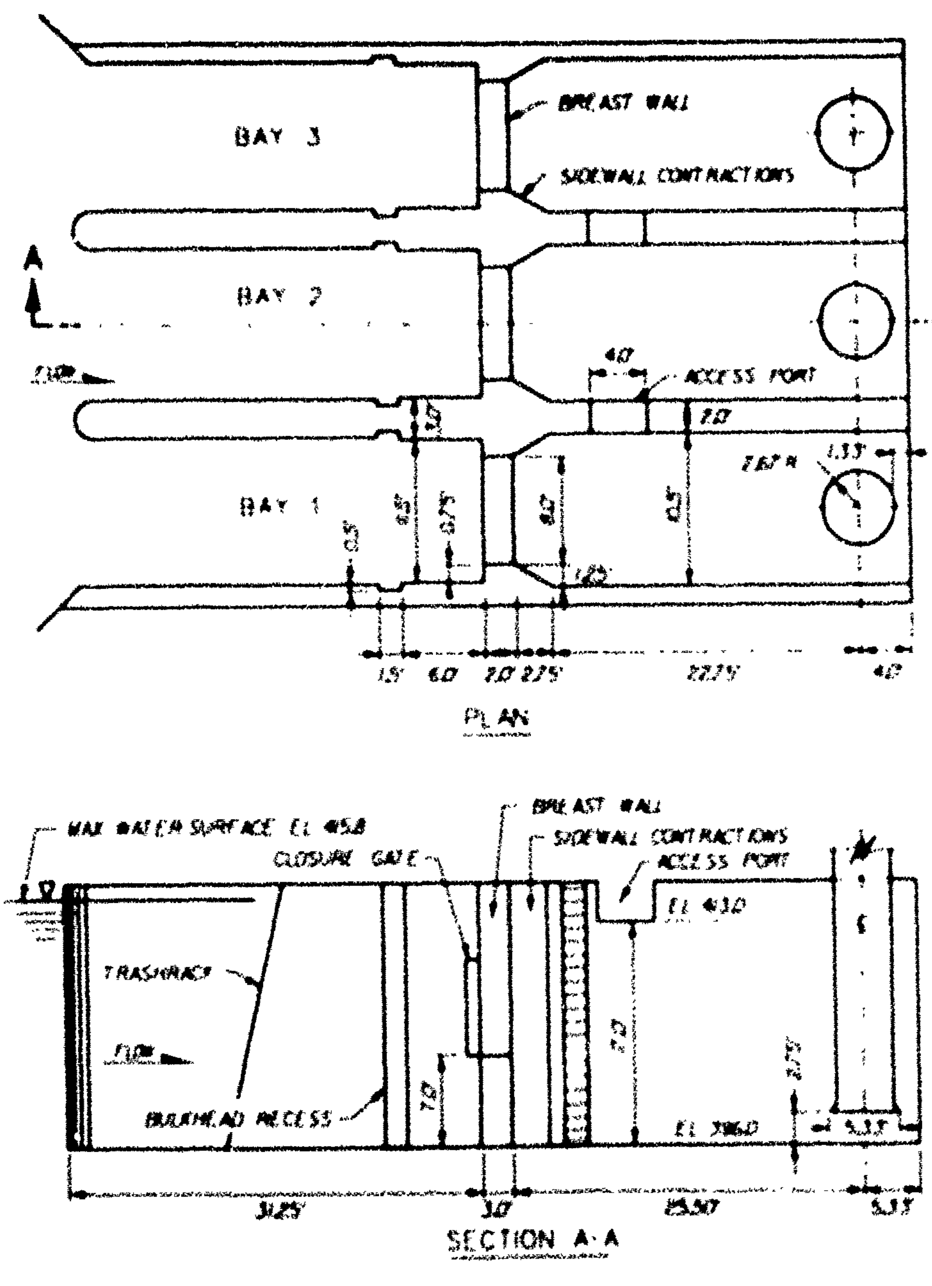


FLOW PATTERNS
TYPE 1 DESIGN SUMP
WATER-SURFACE EL 405.0
ALL PUMPS OPERATING
DISCHARGE PER PUMP 112 CFS

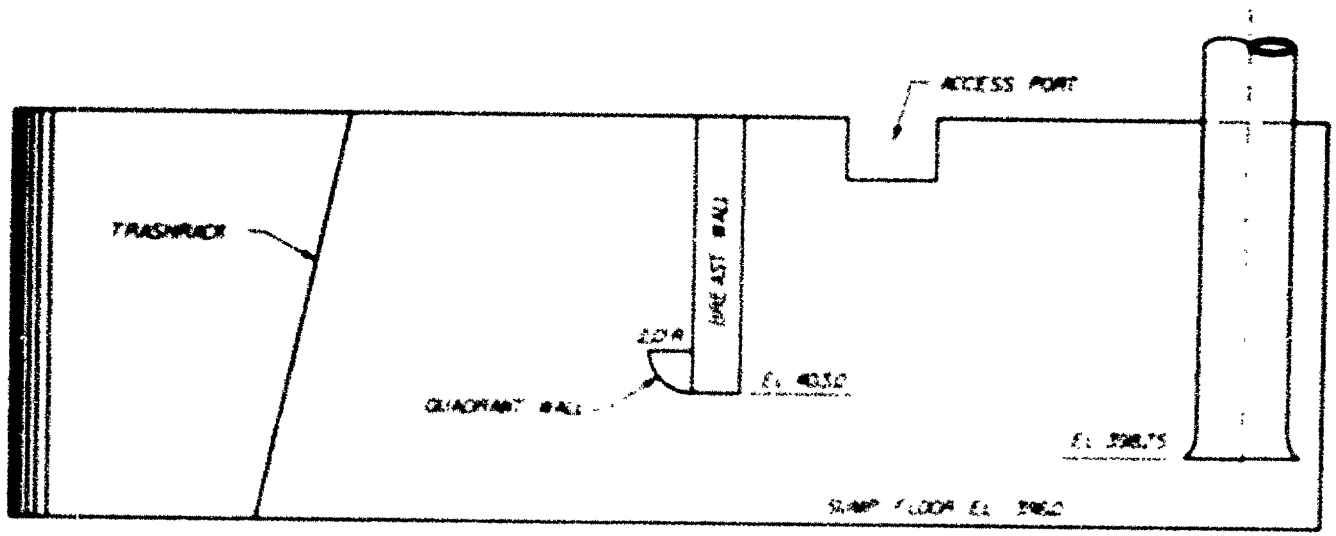


FLOW PATTERNS
TYPE 1 DESIGN SUMP

PLATE 6



ORIGINAL
TYPE 1 DESIGN SUMP



ELEVATION

TYPE 5 DESIGN SUMP

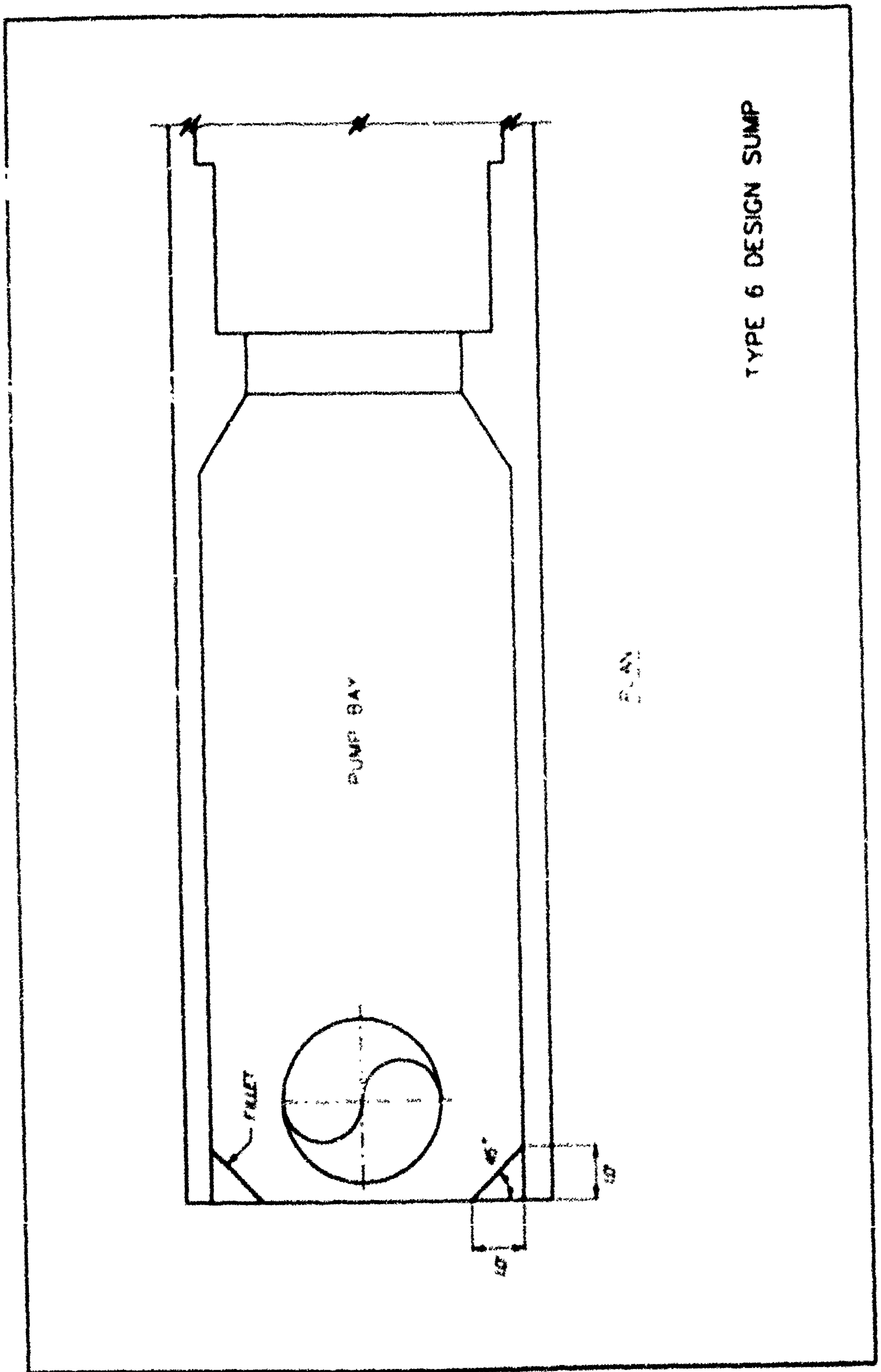
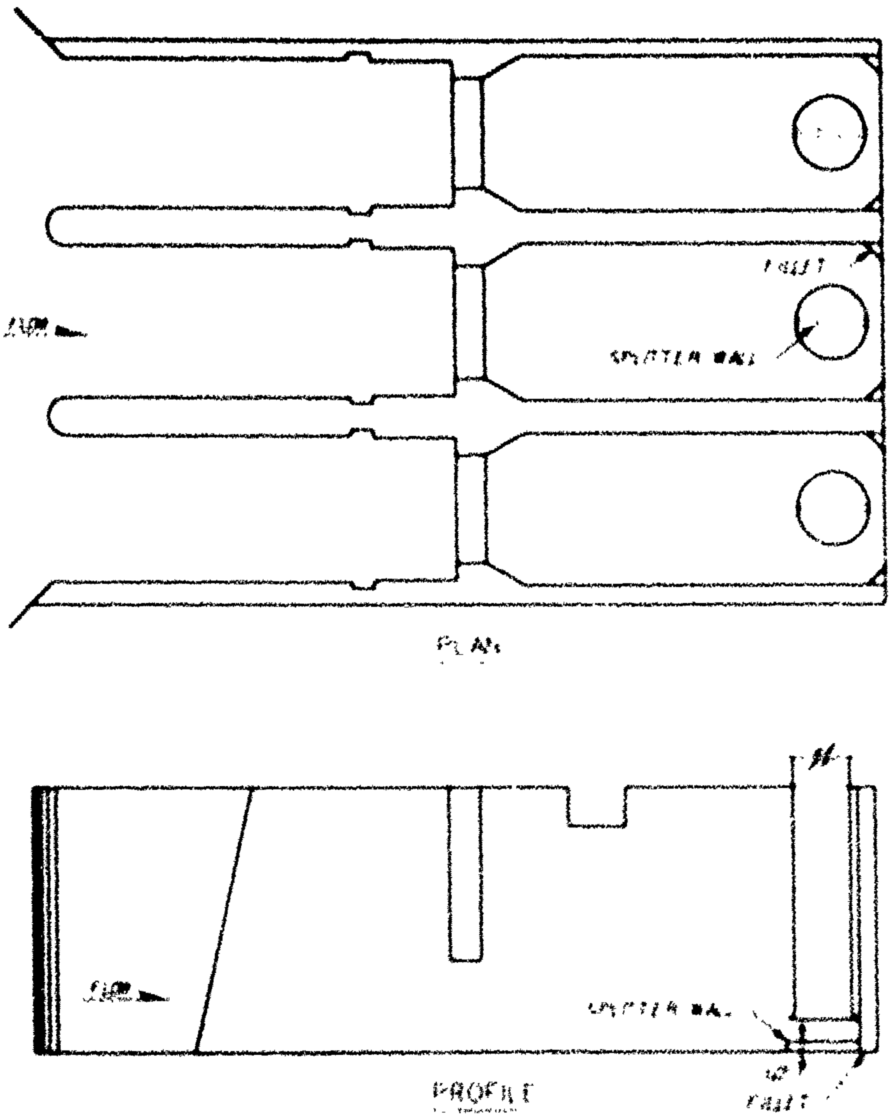
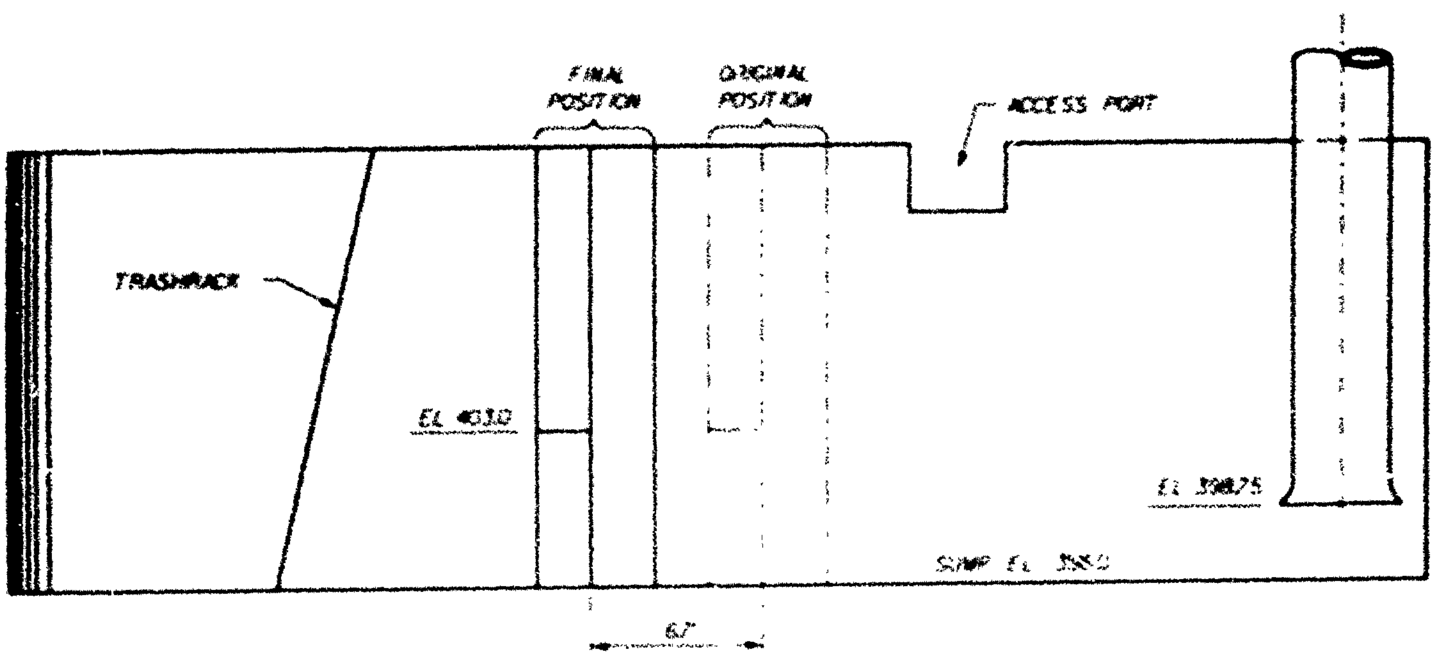


PLATE 9



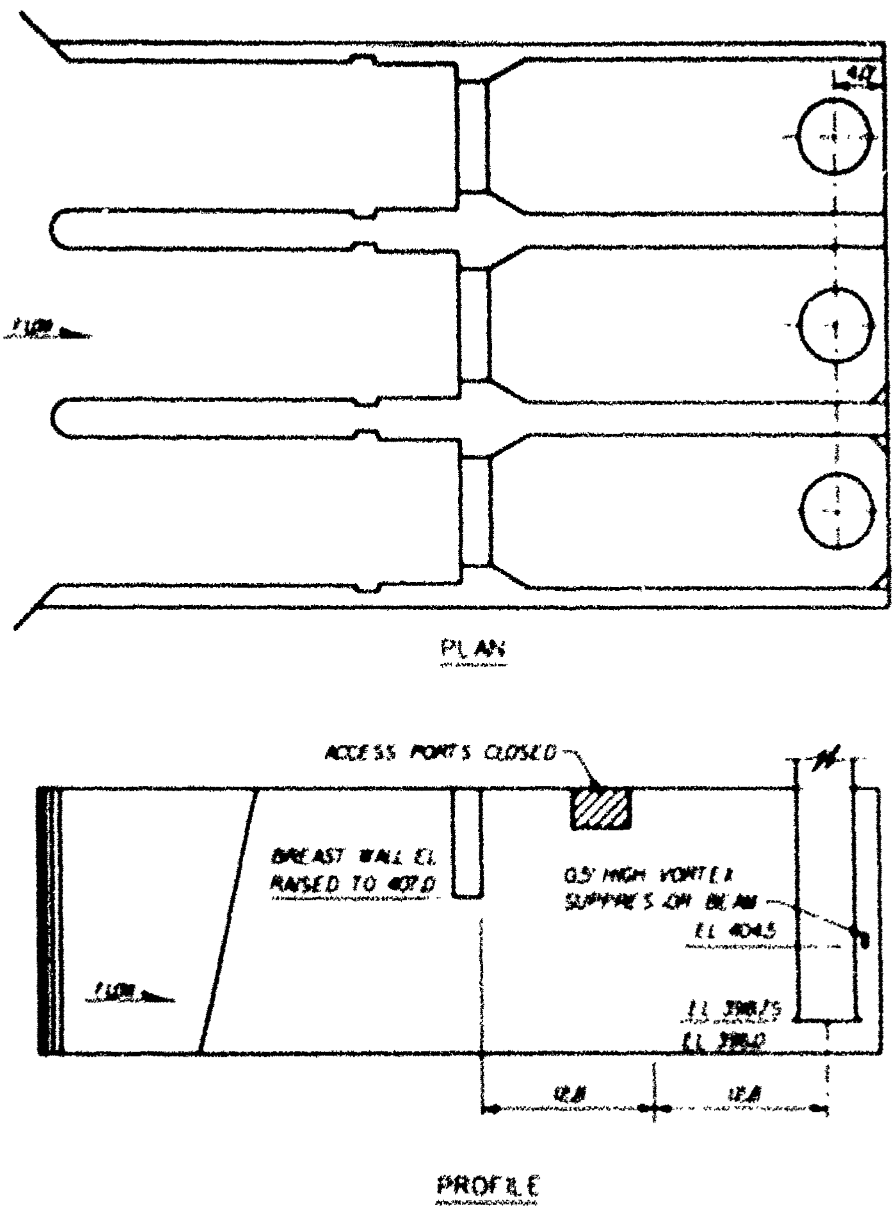
TYPE 7 DESIGN SUMP

PLATE 10



PLAN

TYPE 8 DESIGN SUMP



TYPE 16 DESIGN SUMP

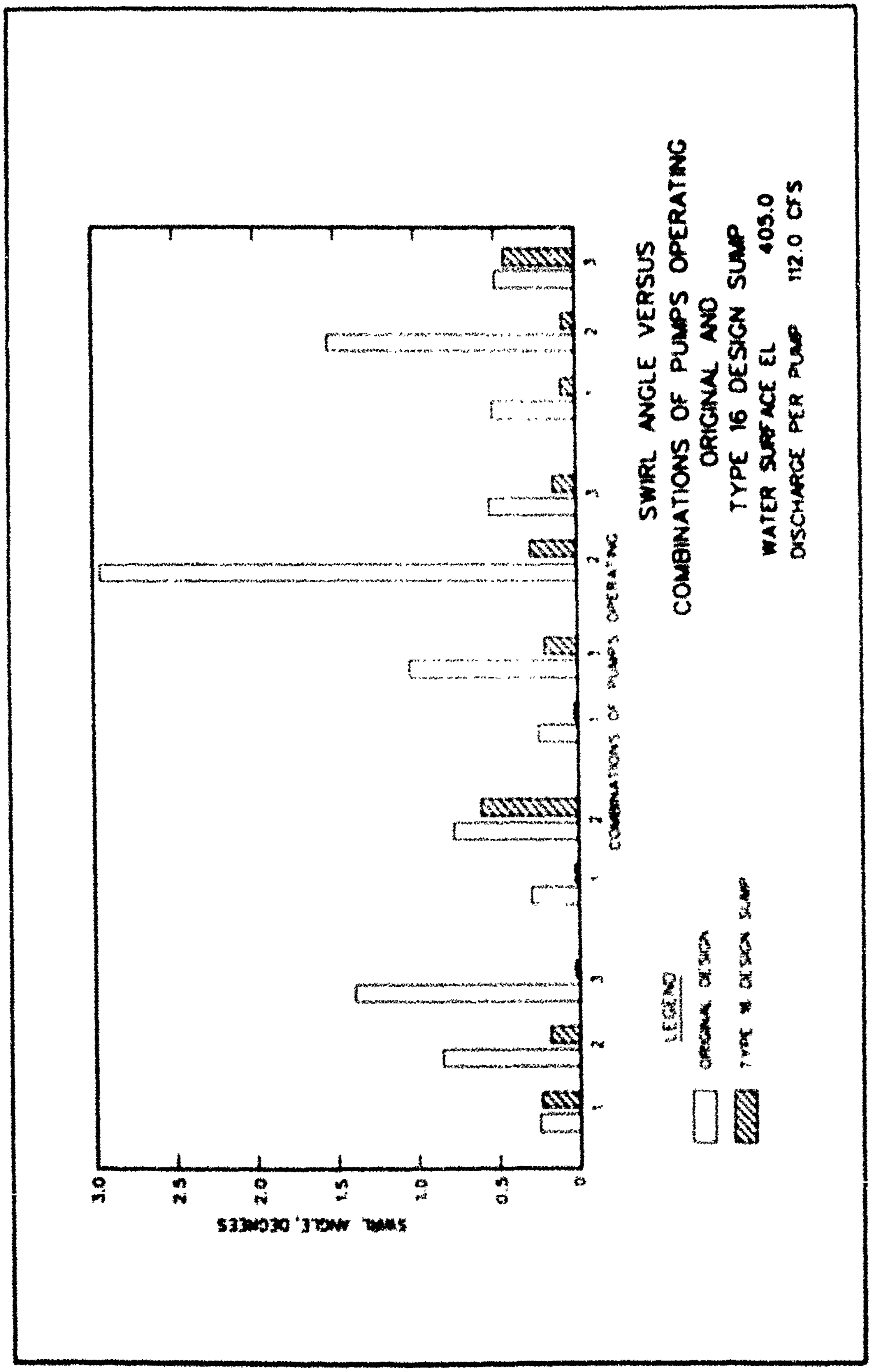
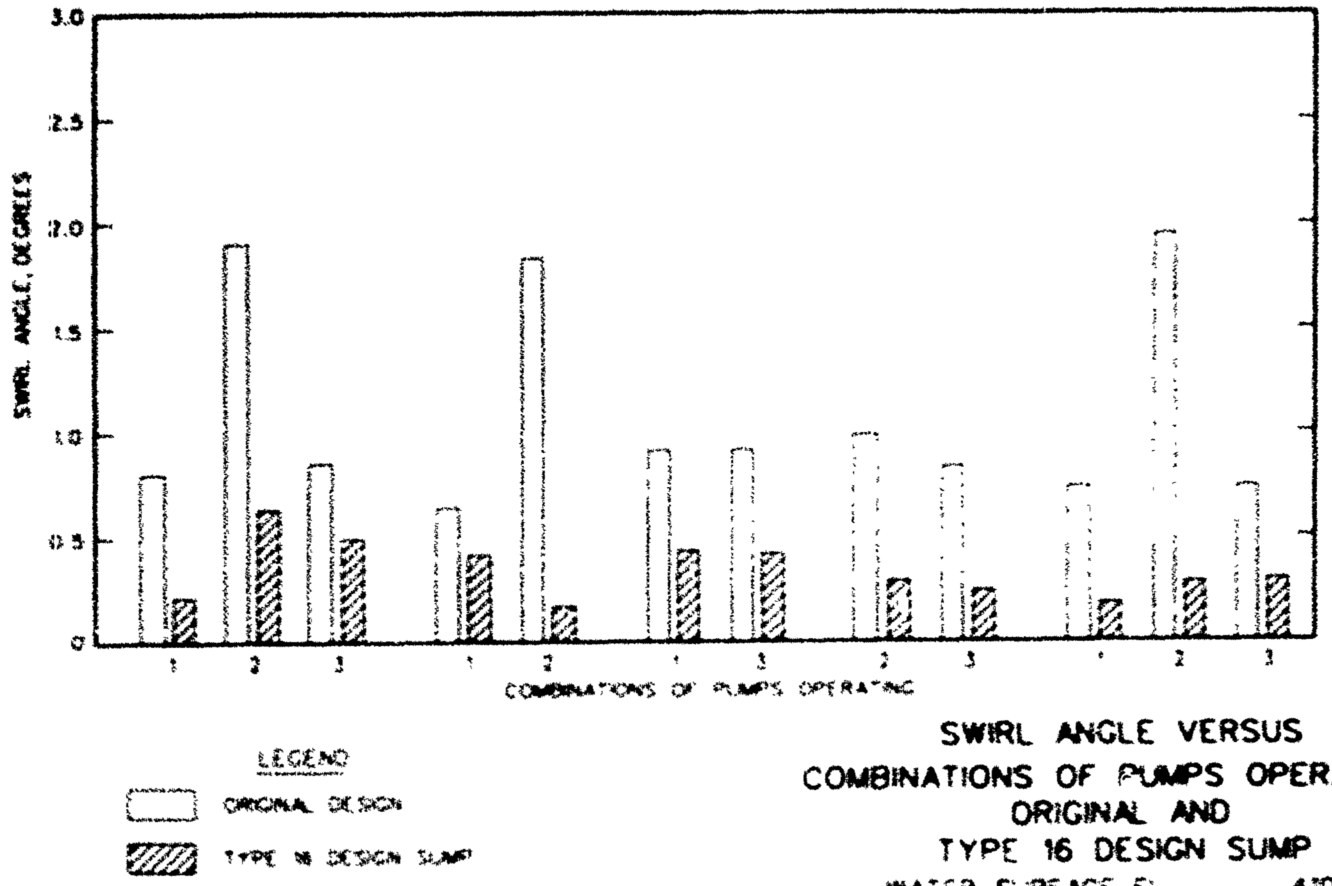
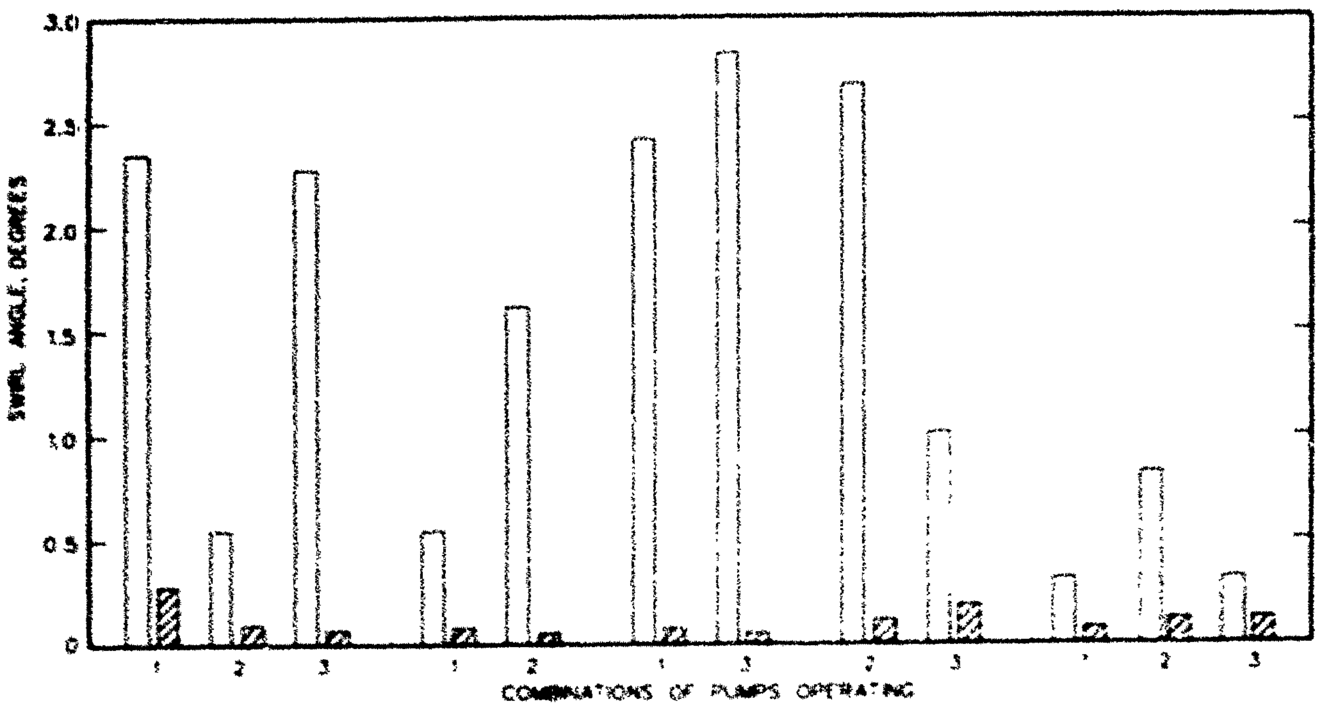

SWIRL ANGLE VERSUS
COMBINATIONS OF PUMPS OPERATING
ORIGINAL AND
TYPE 16 DESIGN SUMP
WATER SURFACE EL 405.0
DISCHARGE PER PUMP 112.0 CFS
SWIRL ANGLE, DEGREES
0
0.5
1.0
1.5
2.0
2.5
3.0
COMBINATIONS OF PUMPS OPERATING
LEGEND
ORIGINAL DESIGN
TYPE 16 DESIGN SUMP

PLATE 13



SWIRL ANGLE VERSUS
COMBINATIONS OF PUMPS OPERATING
ORIGINAL AND
TYPE 16 DESIGN SUMP

WATER SURFACE EL 410.0
DISCHARGE PER PUMP 112.0 CFS



LEGEND

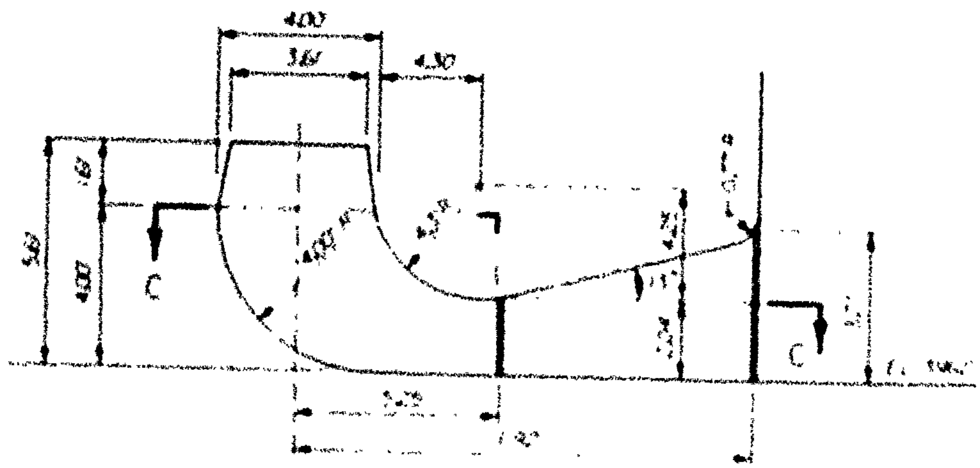
ORIGINAL DESIGN

TYPE 16 DESIGN SUMP

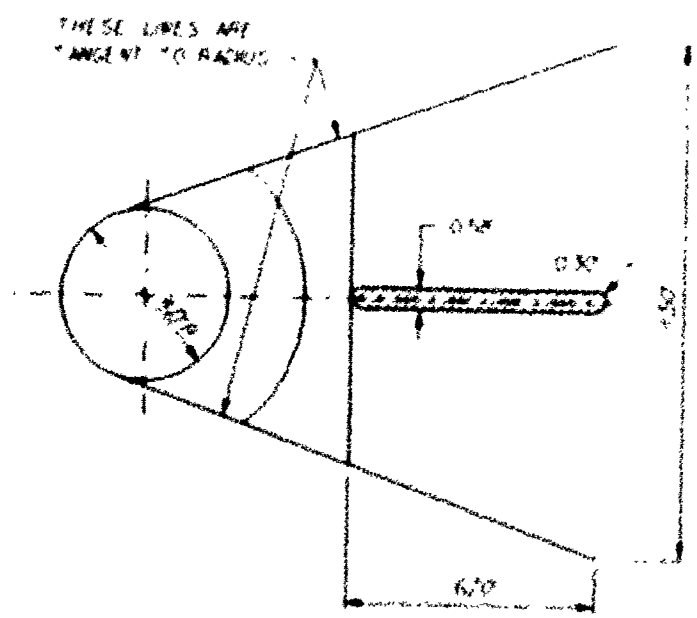
SWIRL ANGLE VERSUS
COMBINATIONS OF PUMPS OPERATING
ORIGINAL AND
TYPE 16 DESIGN SUMP

WATER SURFACE EL 415.0

DISCHARGE PER PUMP 112.0 CFS



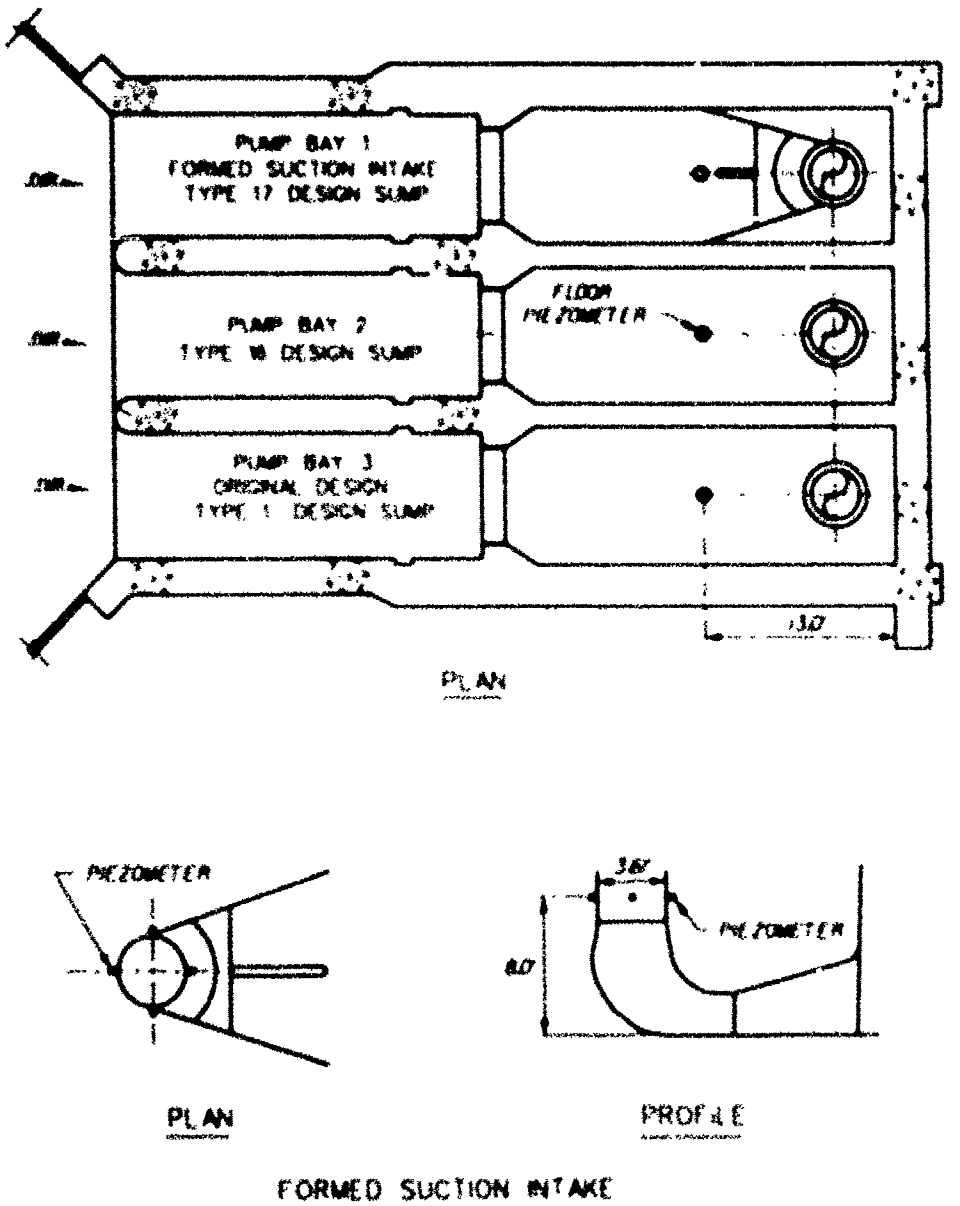
PLAN



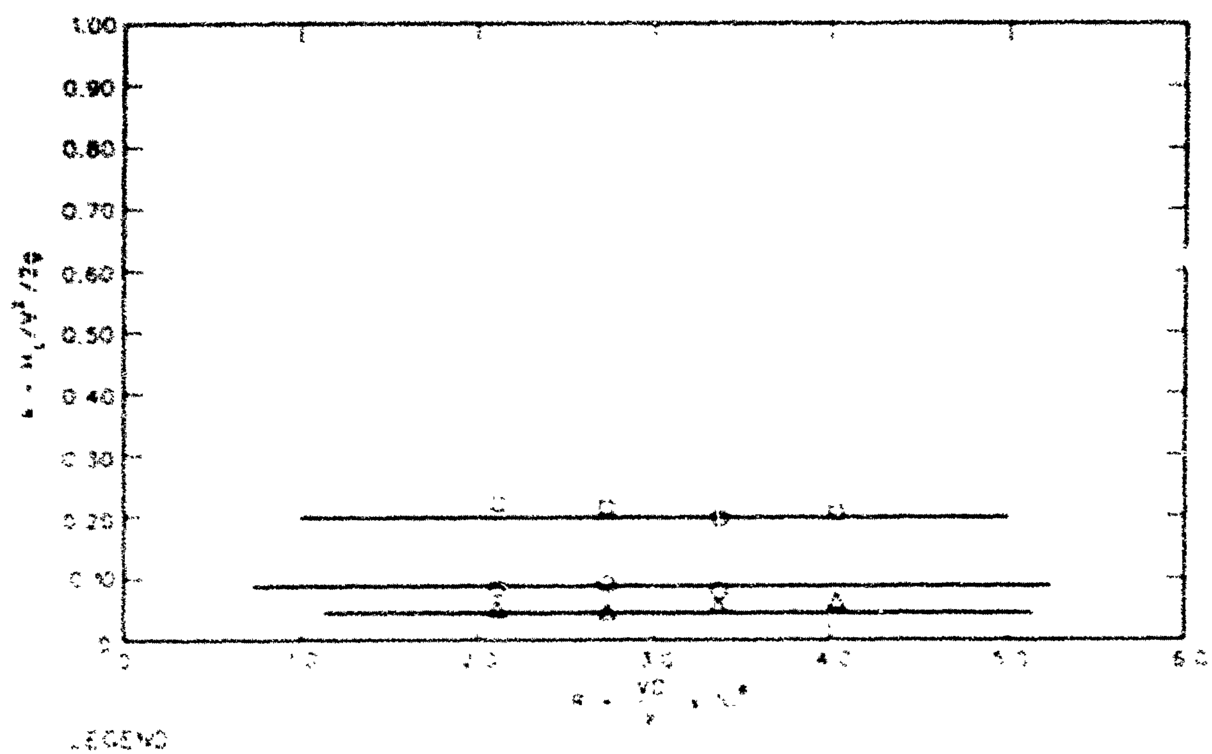
SECTION C C

FORMED SUCTION INTAKE

PLATE 16



PIEZOMETER LOCATIONS FOR MEASUREMENT OF HEAD LOSS

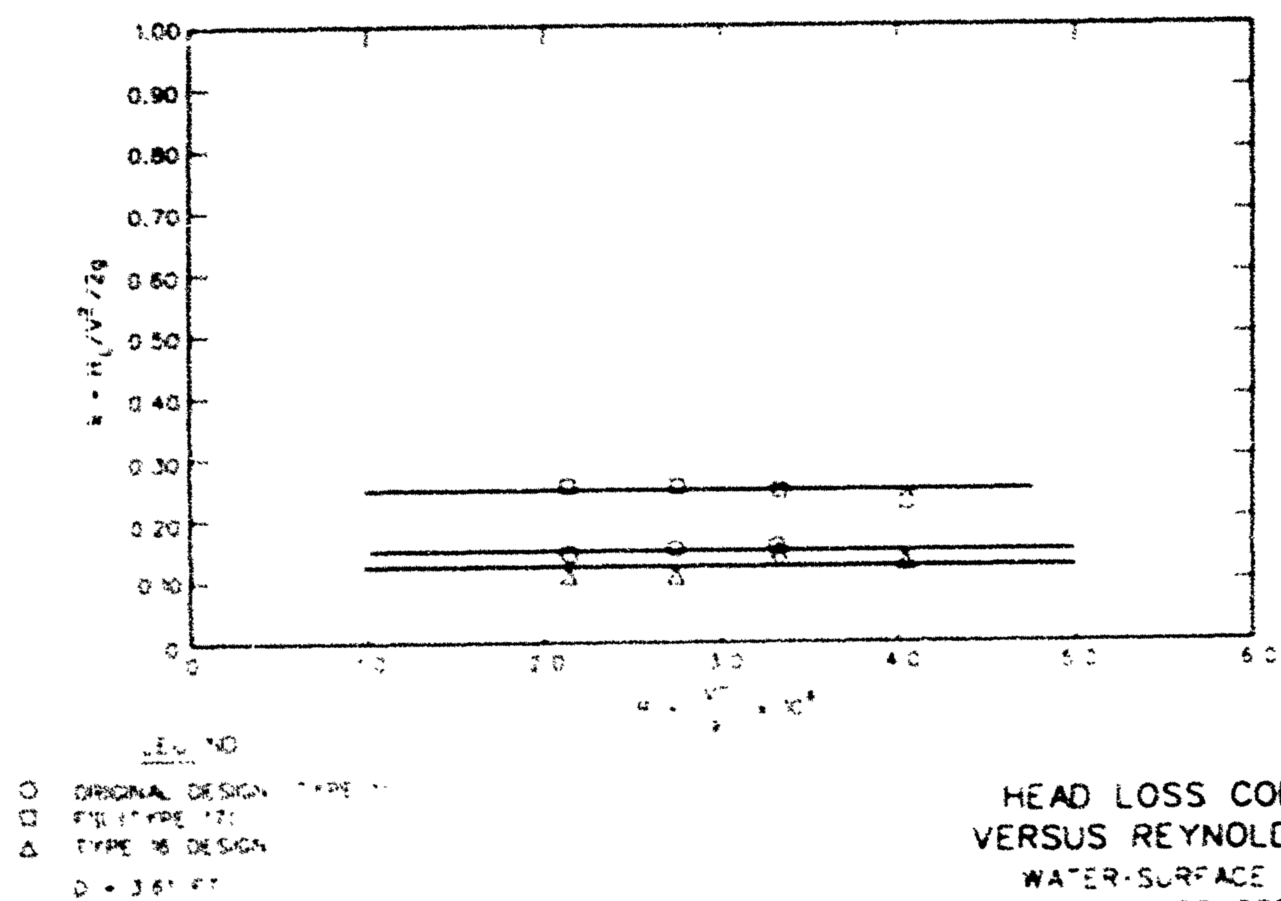


LEGEND

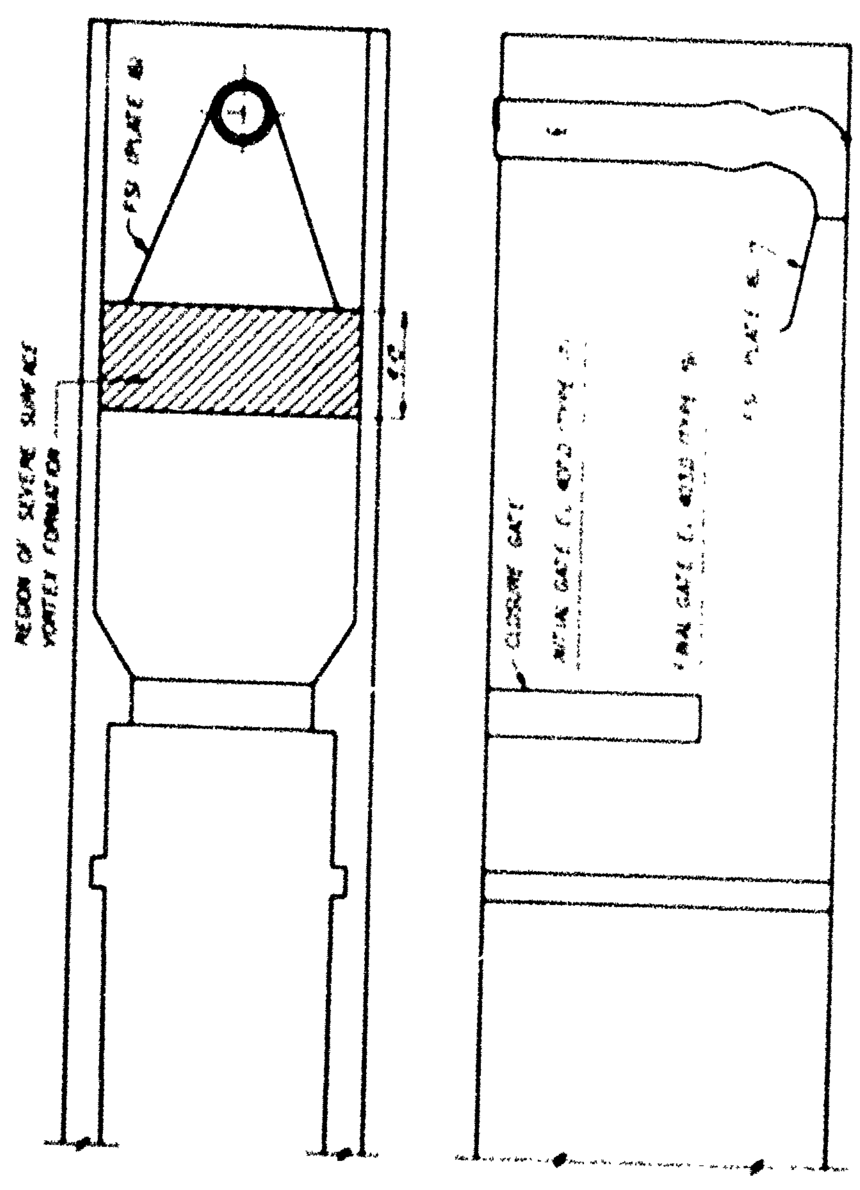
O ORIGINAL DESIGN (TYPE 1)
□ ES (TYPE 17)
Δ TYPE 18 DESIGN

D = 3.6 FT

HEAD LOSS COEFFICIENT
VERSUS REYNOLD'S NUMBER
WATER-SURFACE EL 405.0
ALL PUMPS OPERATING
DISCHARGE PER PUMP 112 CFS

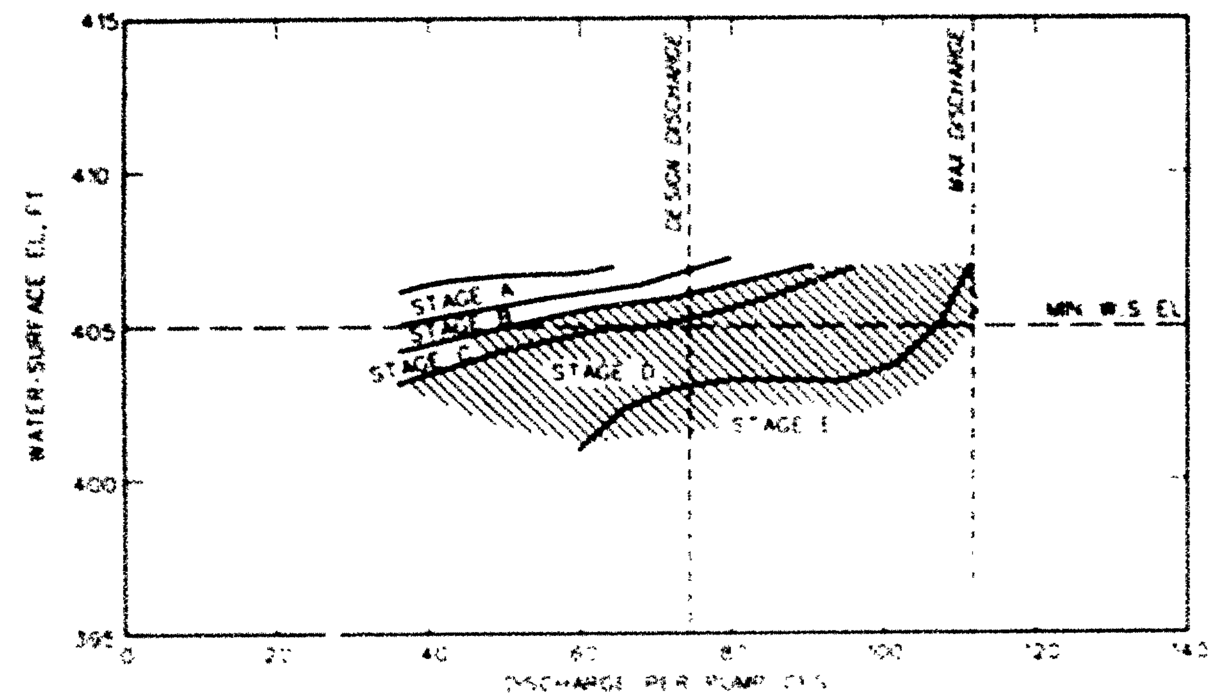


HEAD LOSS COEFFICIENT
VERSUS REYNOLD'S NUMBER
WATER-SURFACE EL 413.0
ALL PUMPS OPERATING
DISCHARGE PER PUMP 112 CFS



SECTION MODEL
SURFACE VORTICES
TYPES 17 AND 19 DESIGN SUMPS

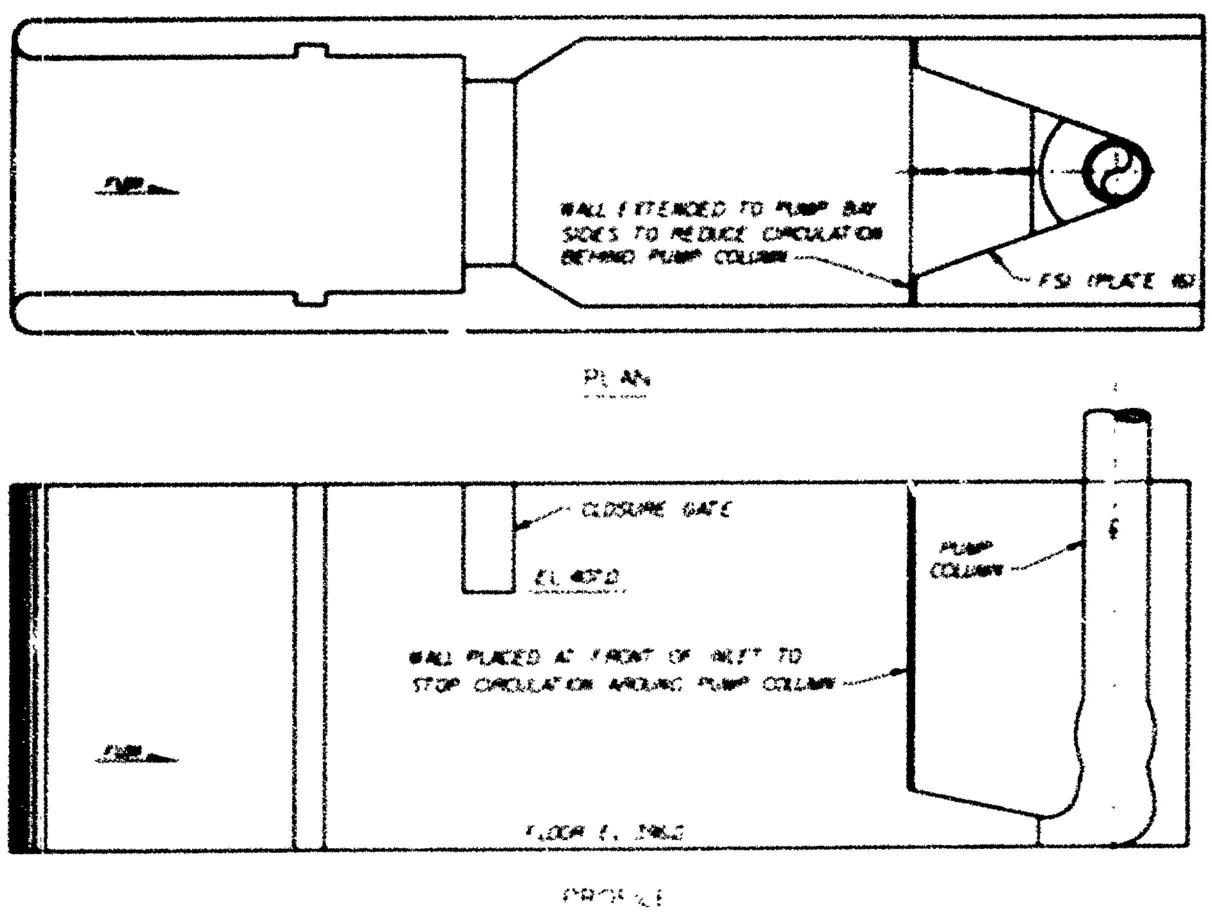
PLATE 20



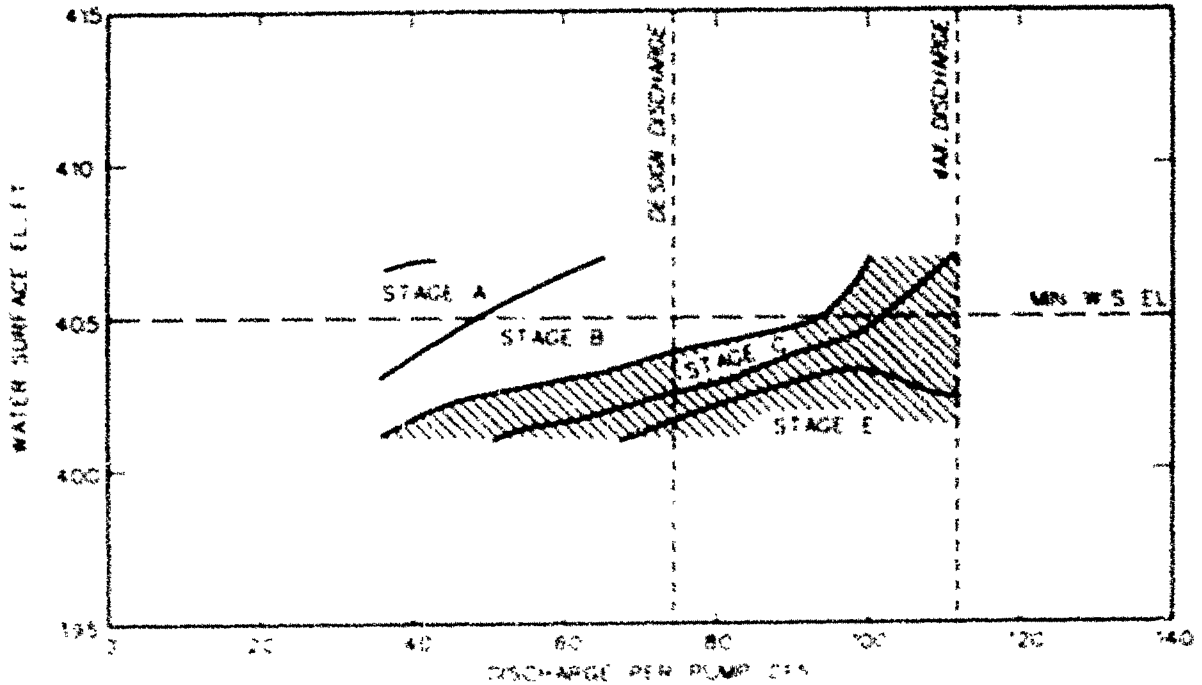
LEGEND

UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

SURFACE VORTICES
SECTION MODEL
TYPE 17 DESIGN SUMP
TRASHRACK; NO BLOCKAGE



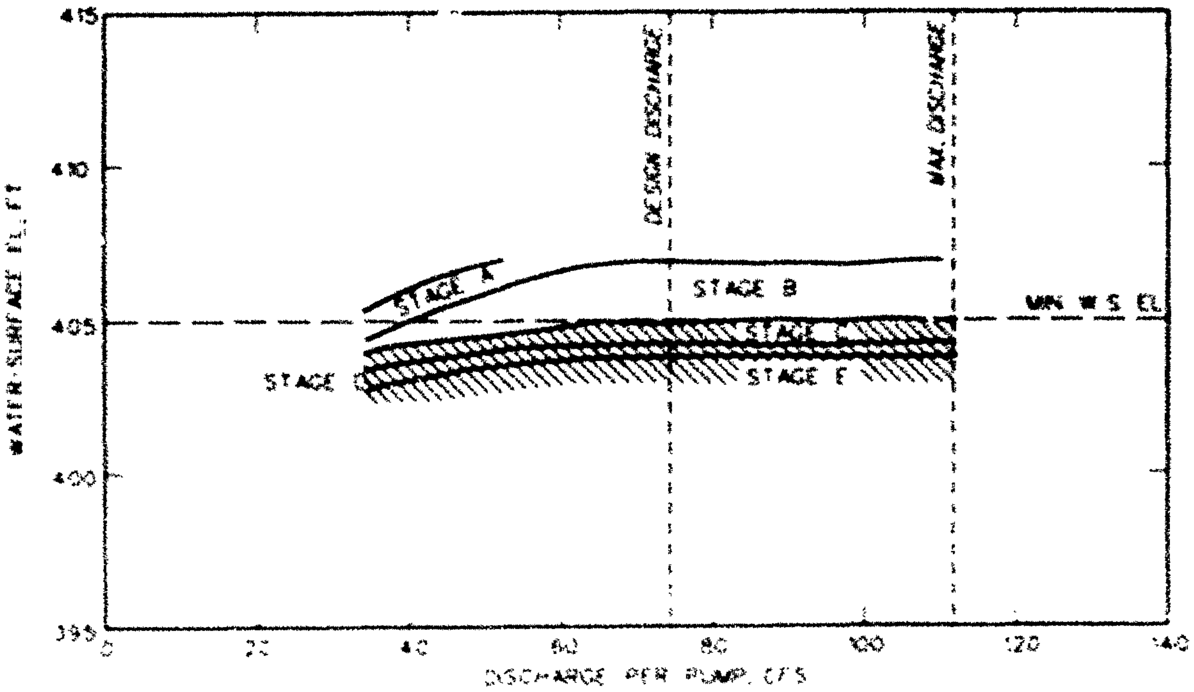
TYPE 18 DESIGN SUMP



LEGEND

UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

SURFACE VORTICES
SECTION MODEL
TYPE 18 DESIGN SUMP
TRASHRACK: NO BLOCKAGE

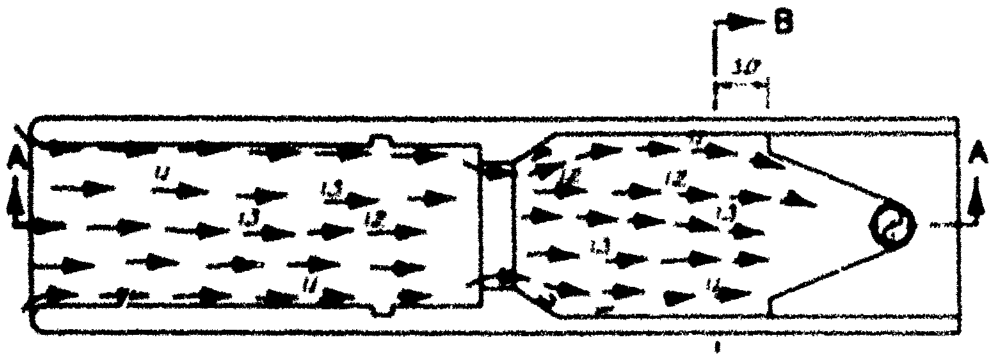


LEGEND

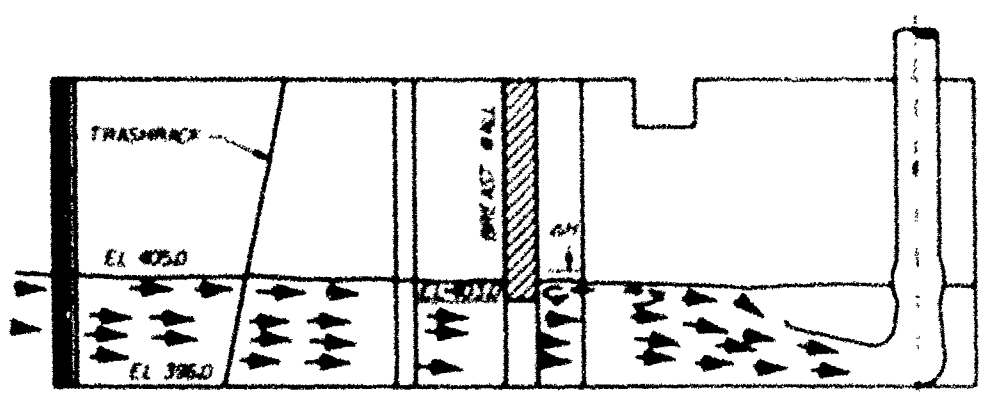
UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

SURFACE VORTICES
SECTION MODEL
TYPE 19 DESIGN SUMP
TRASHRACK: NO BLOCKAGE

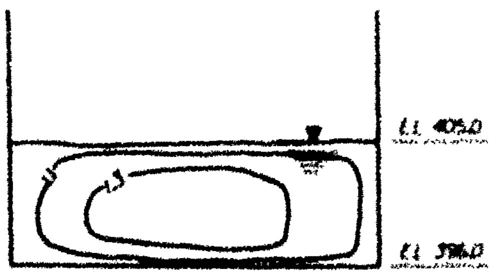
PLATE 24



PLAN



SECTION A-A

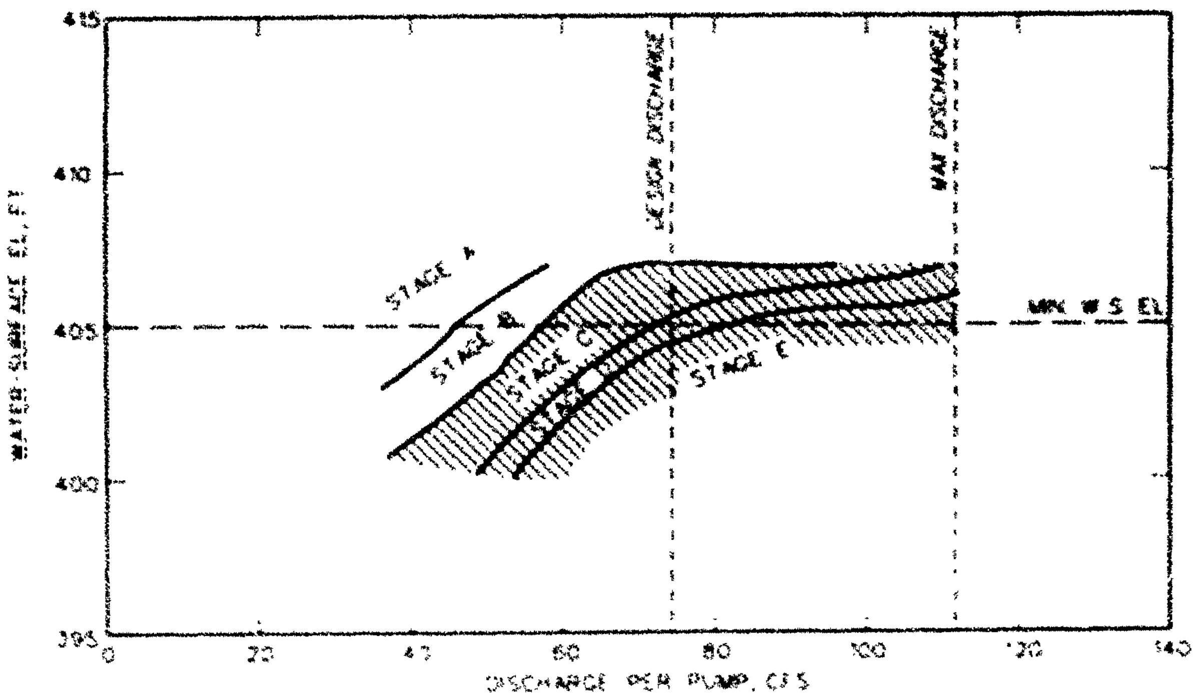


SECTION B-B

DISCHARGE CFS	WATER SURFACE EL FT	ΔH, FT
112	405	0.[illegible]
74	405	0.07

NOTE: VELOCITIES IN PLAN VIEW WERE MEASURED 1 FT ABOVE THE BOTTOM

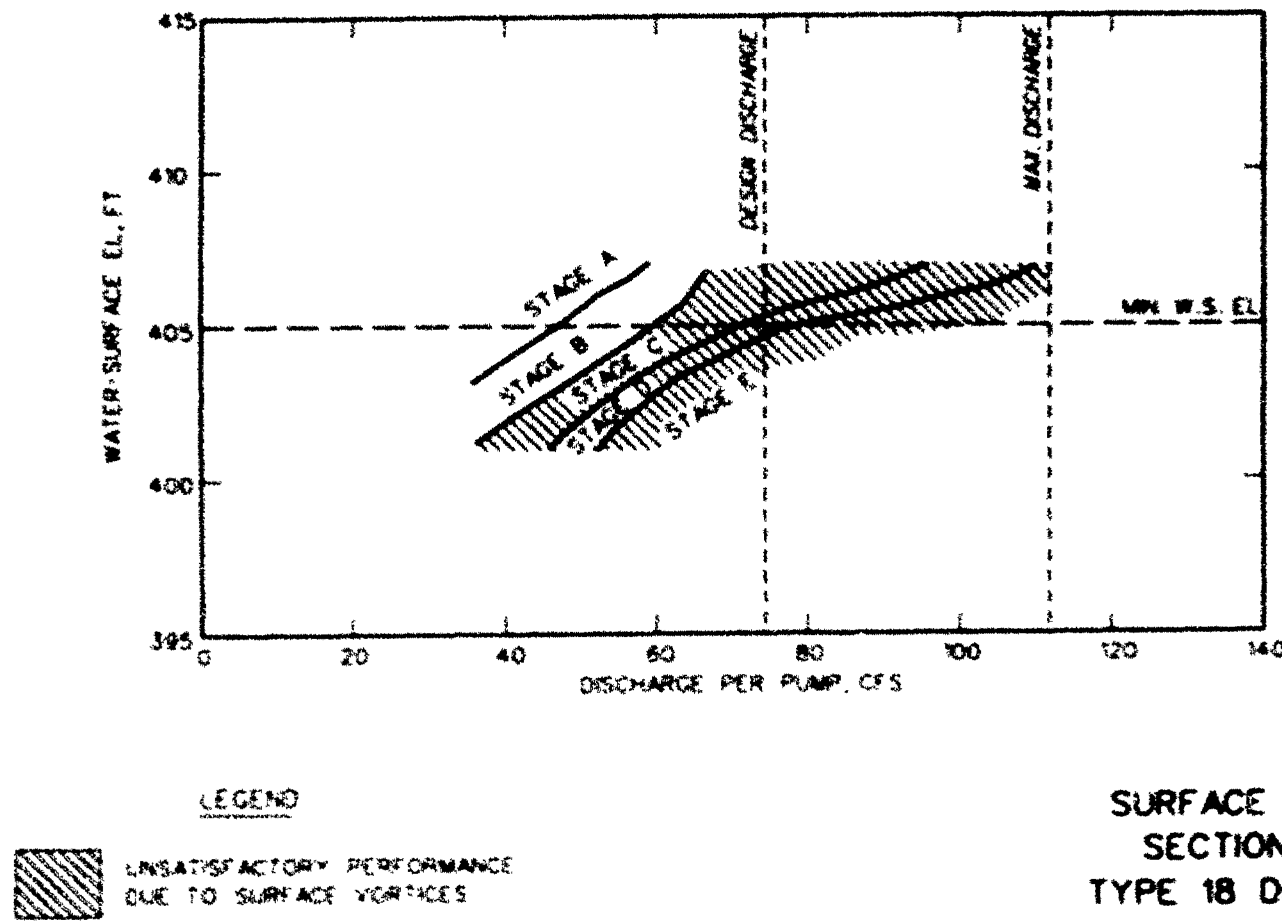
HEAD LOSS AND APPROACH VELOCITIES TYPE 19 DESIGN SUMP



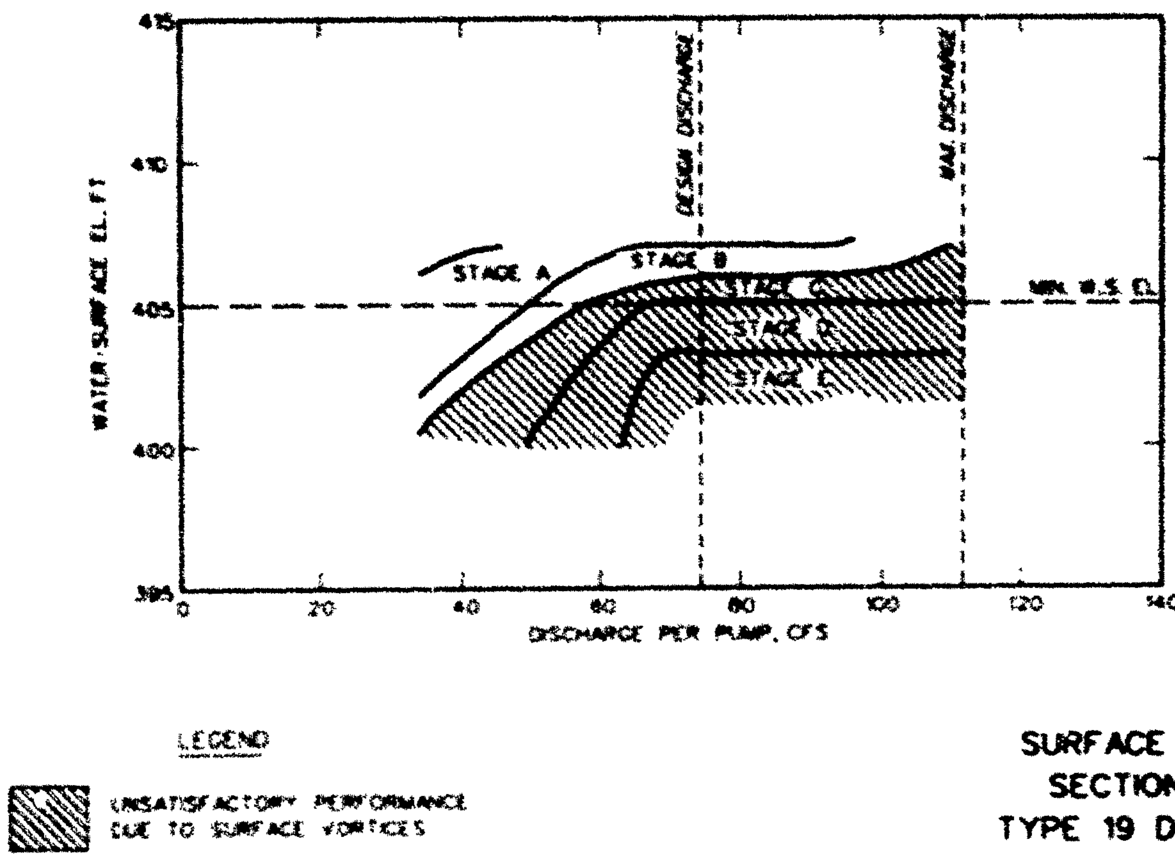
LEGEND

UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

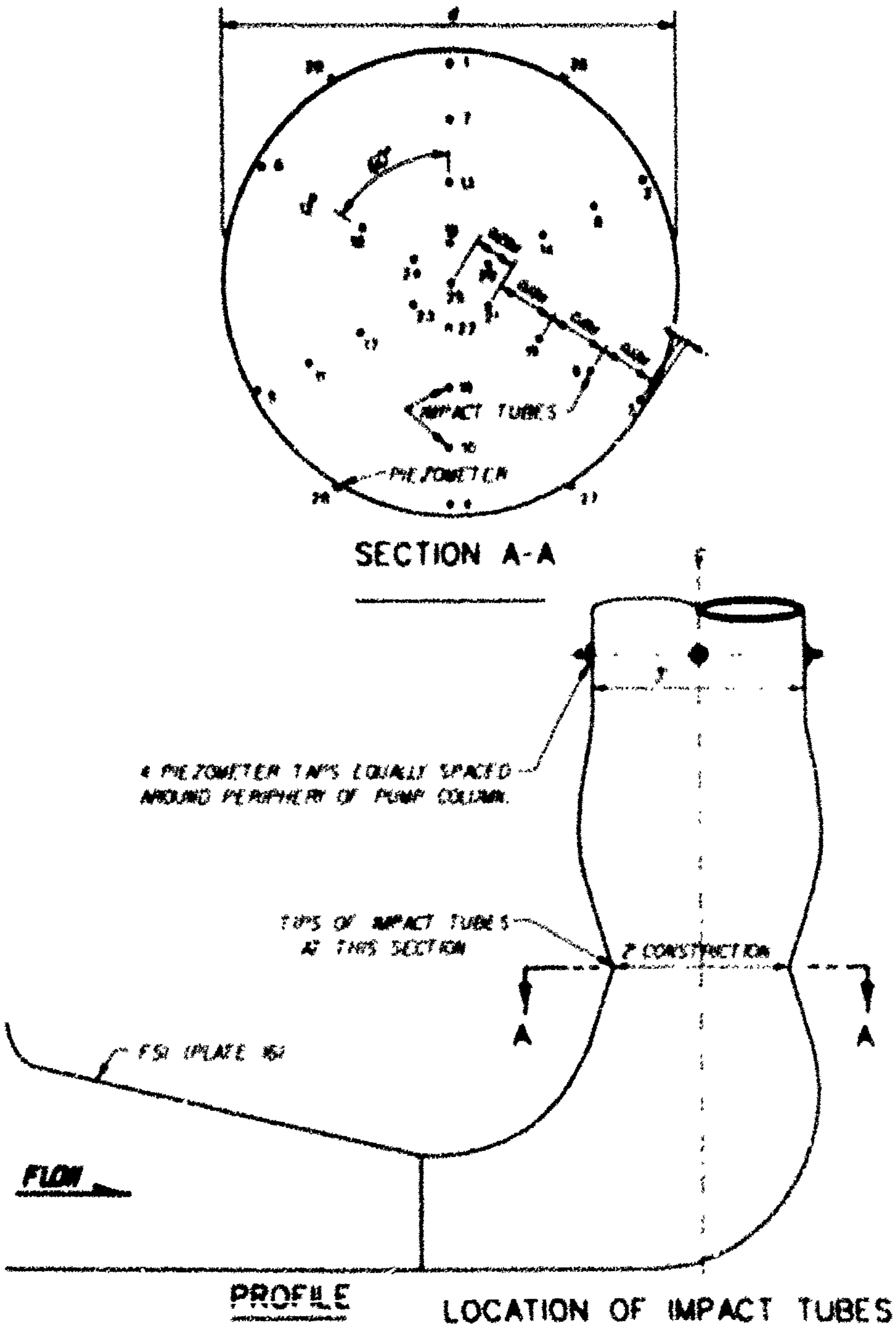
SURFACE VORTICES
SECTION MODEL
TYPE 17 DESIGN SUMP
TRASHRACK: 25% BLOCKAGE



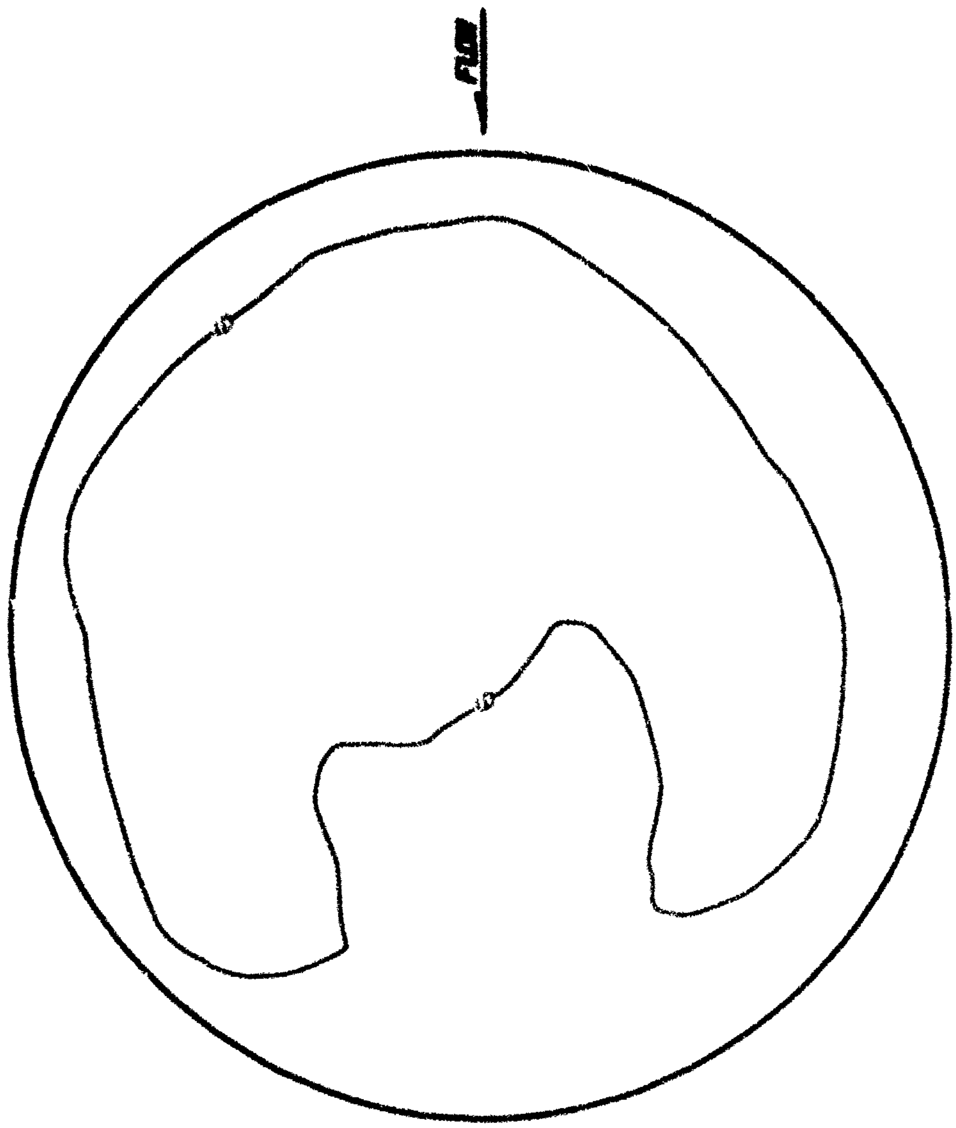
SURFACE VORTICES
SECTION MODEL
TYPE 18 DESIGN SUMP
TRASHRACK: 25% BLOCKAGE



SURFACE VORTICES
SECTION MODEL
TYPE 19 DESIGN SUMP
TRASHRACK: 25% BLOCKAGE



LOCATION OF IMPACT TUBES
AND PIEZOMETERS
SECTION MODEL
TYPE 19 DESIGN SUMP



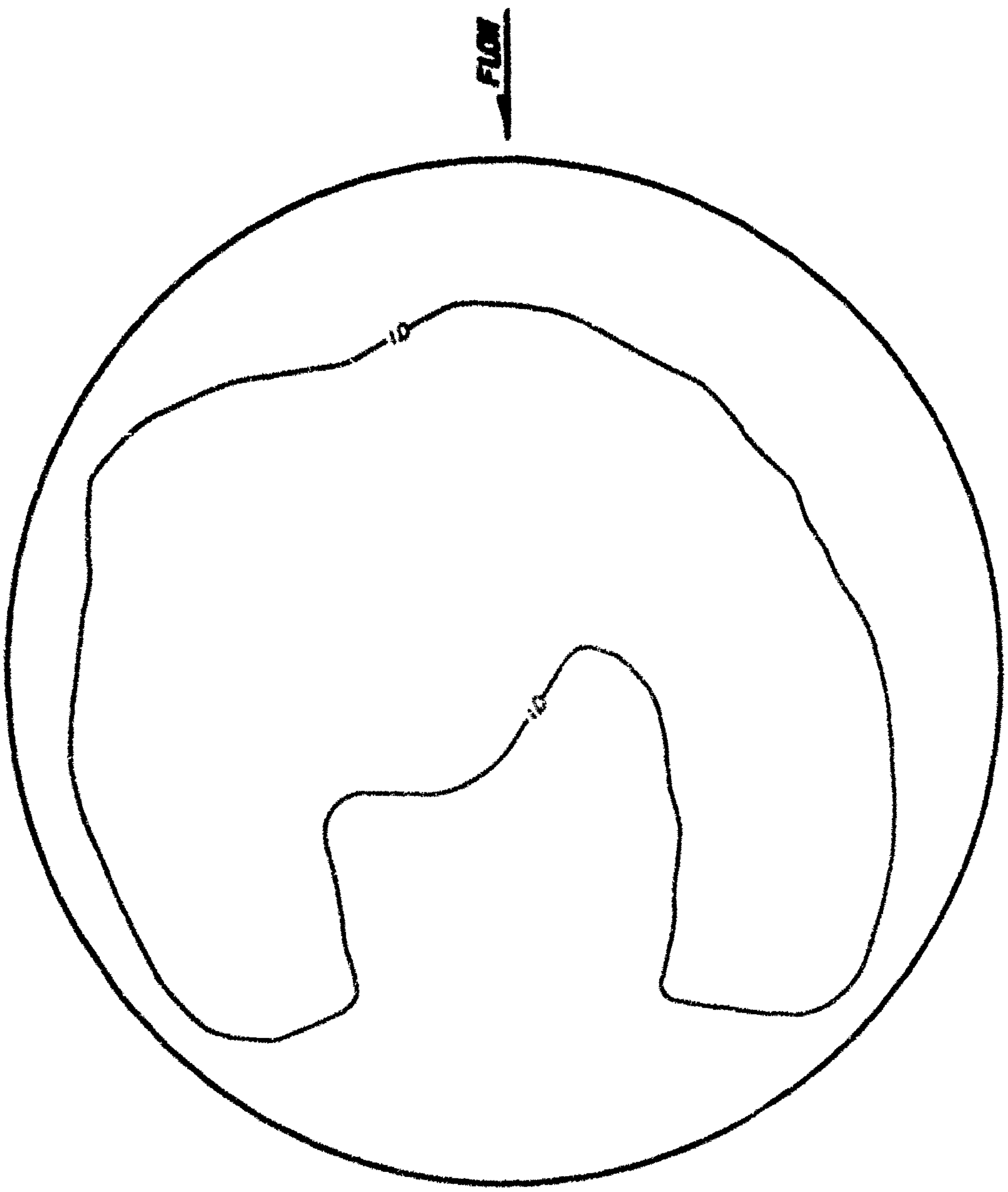
TEST CONDITIONS

WATER SURFACE EL	400.0
DISCHARGE	112 CFS

$R_v = \frac{V_x}{V_0} = \frac{\text{MEASURED AVERAGE AXIAL VELOCITY}}{\text{COMPUTED AVERAGE AXIAL VELOCITY}}$

$V_0 = \frac{Q}{A} = \frac{\text{DISCHARGE}}{\text{AREA OF PUMP COLUMN CROSS SECTION}}$

LINES OF EQUAL VELOCITY RATIOS
TYPE 17 DESIGN SUMP
AVERAGE VALUES R_V

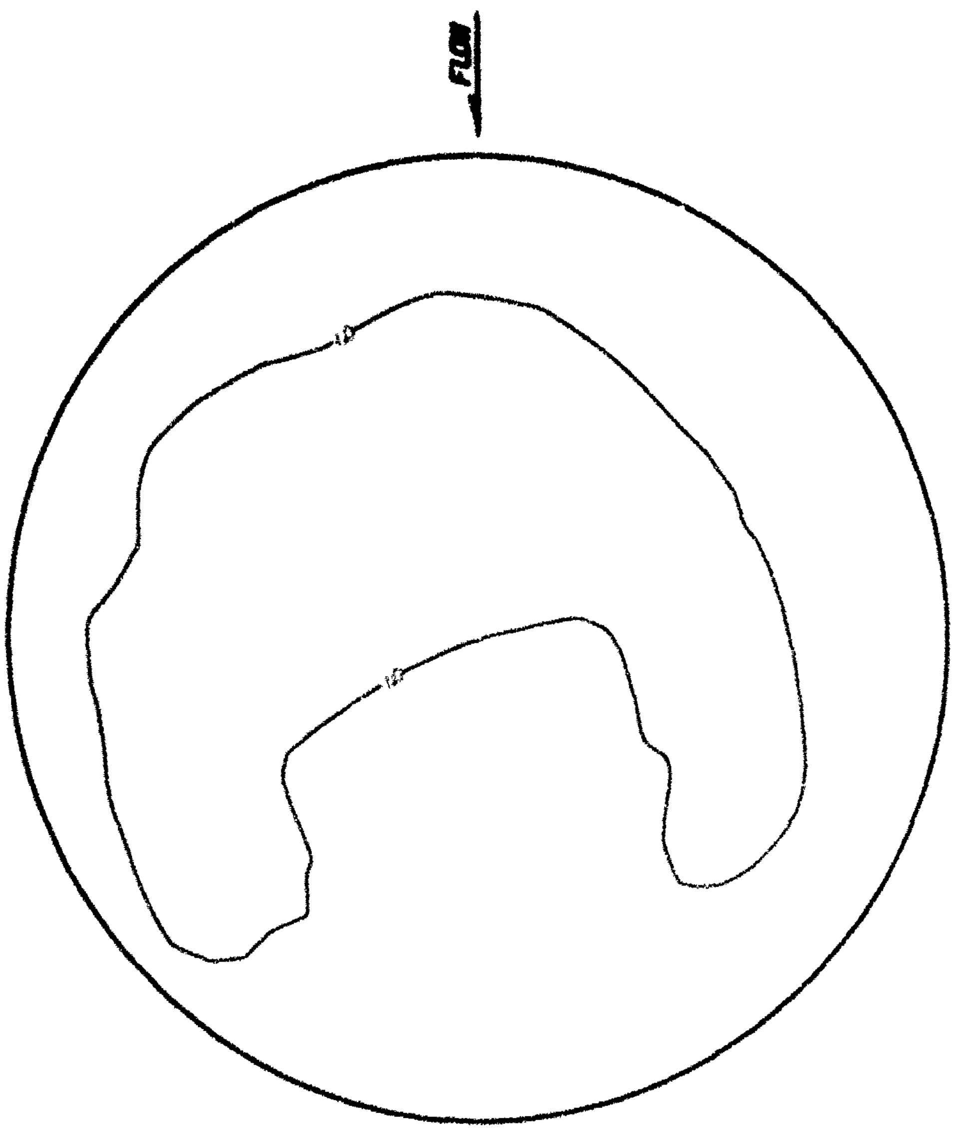


TEST CONDITIONS	
WATER SURFACE EL	405.0
DISCHARGE	112 CFS

$$R_v = \frac{V_m}{V_c} = \frac{\text{MEASURED AVERAGE AXIAL VELOCITY}}{\text{COMPUTED AVERAGE AXIAL VELOCITY}}$$

$$V_c = \frac{Q}{A} = \frac{\text{DISCHARGE}}{\text{AREA OF PUMP COLUMN CROSS SECTION}}$$

LINES OF EQUAL VELOCITY RATIOS
TYPE 19 DESIGN SUMP
AVERAGE VALUES R_V



TEST CONDITIONS

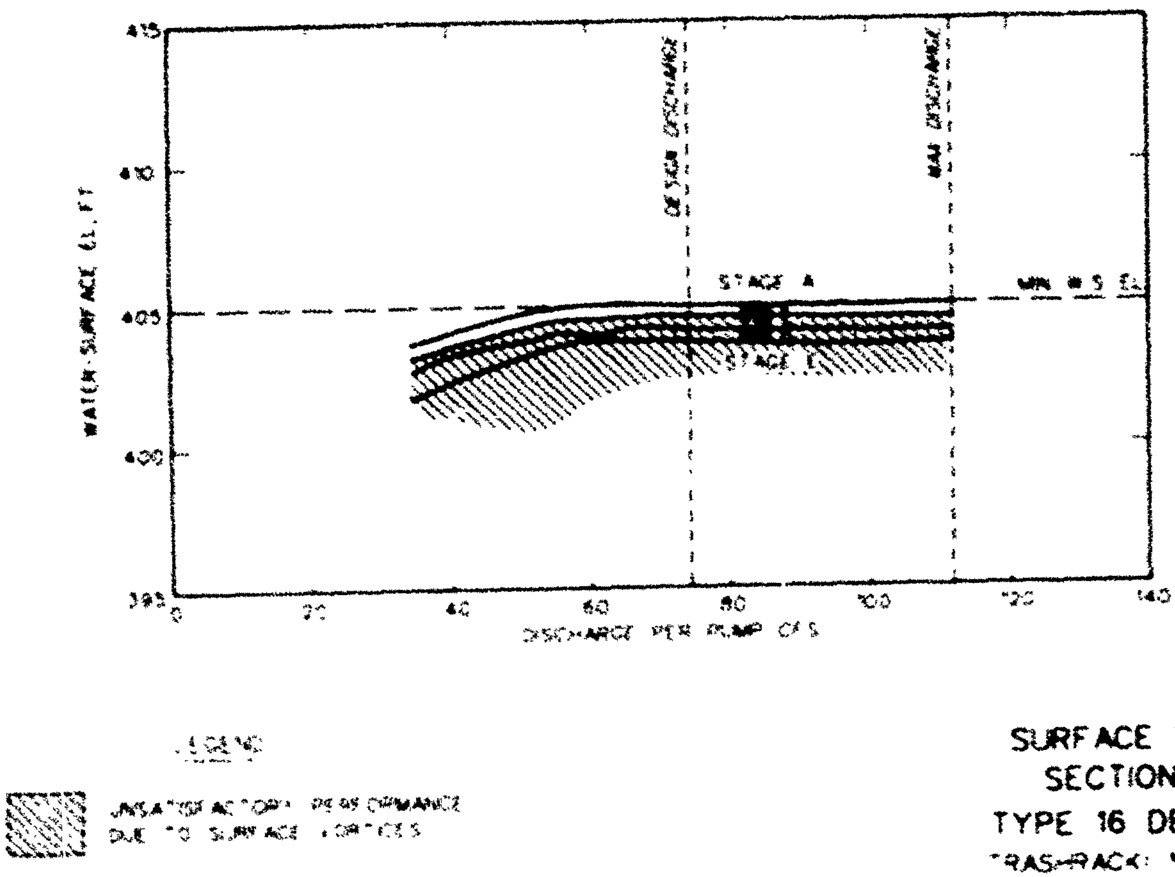
WATER SURFACE EL [illegible]

DISCHARGE [illegible] CFS

$R_V = \frac{V_m}{V_c} = \frac{\text{MEASURED AVERAGE AXIAL VELOCITY}}{\text{COMPUTED AVERAGE AXIAL VELOCITY}}$

$V_c = \frac{Q}{A} = \frac{\text{DISCHARGE}}{\text{AREA OF PUMP COLUMN CROSS SECTION}}$

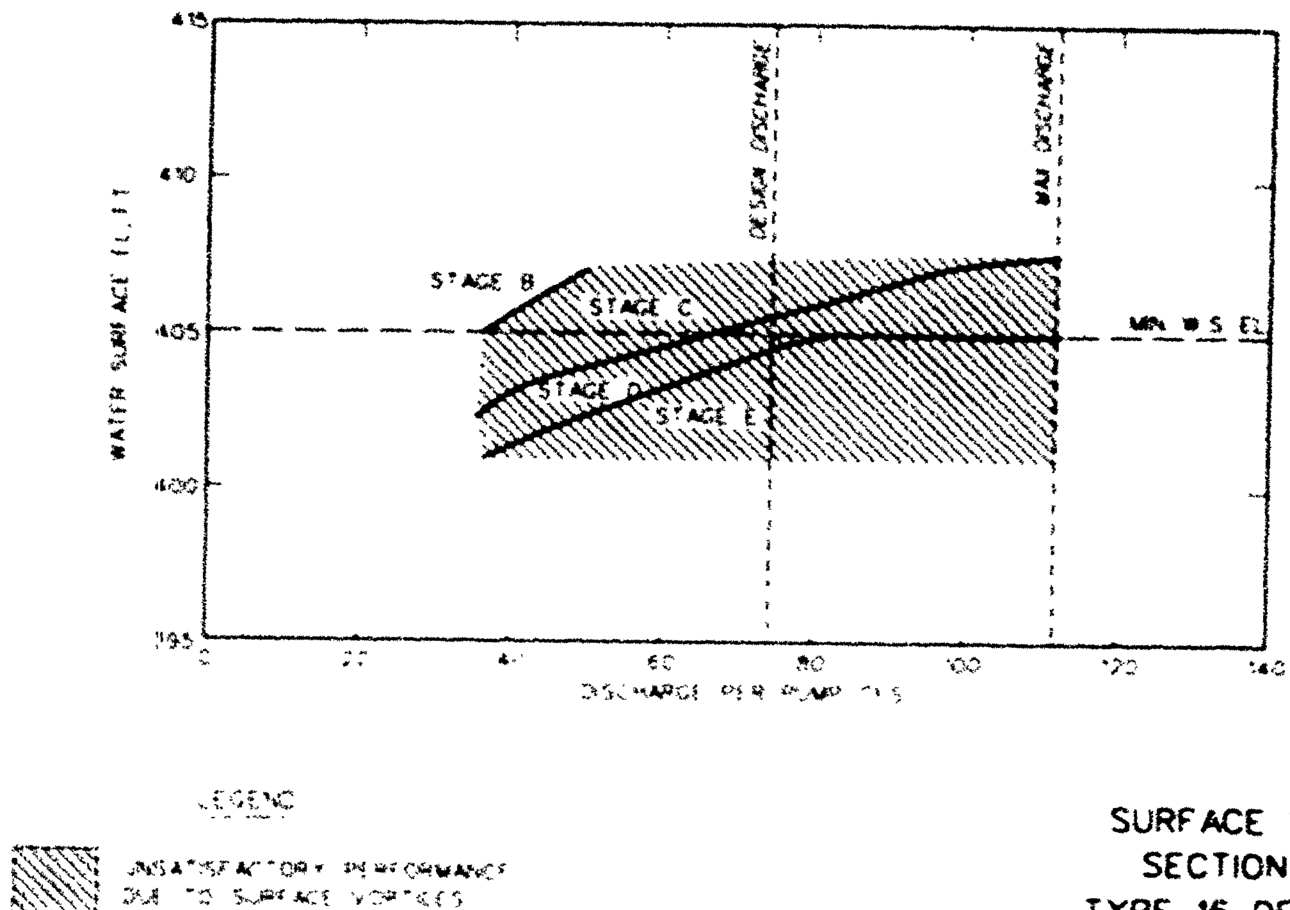
LINES OF EQUAL VELOCITY RATIOS
TYPE 19 DESIGN SUMP
25 PERCENT TRASHRACK BLOCKAGE
PUMP 1
AVERAGE VALUES R_V



LEGEND

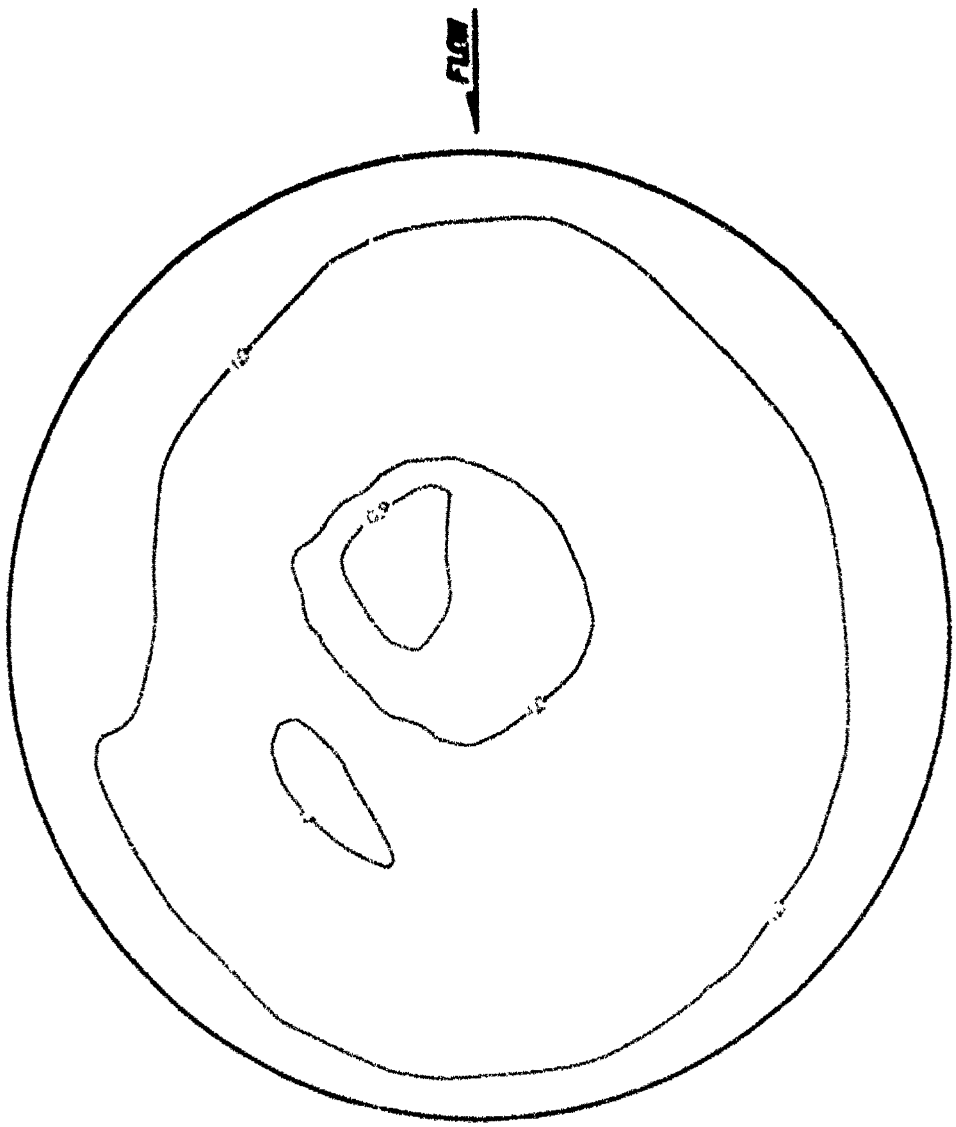
UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

SURFACE VORTICES
SECTION MODEL
TYPE 16 DESIGN SUMP
TRASHRACK: NO BLOCKAGE



SURFACE VORTICES
SECTION MODEL
TYPE 16 DESIGN SUMP
TRASHRACK 25% BLOCKAGE

PLATE 34

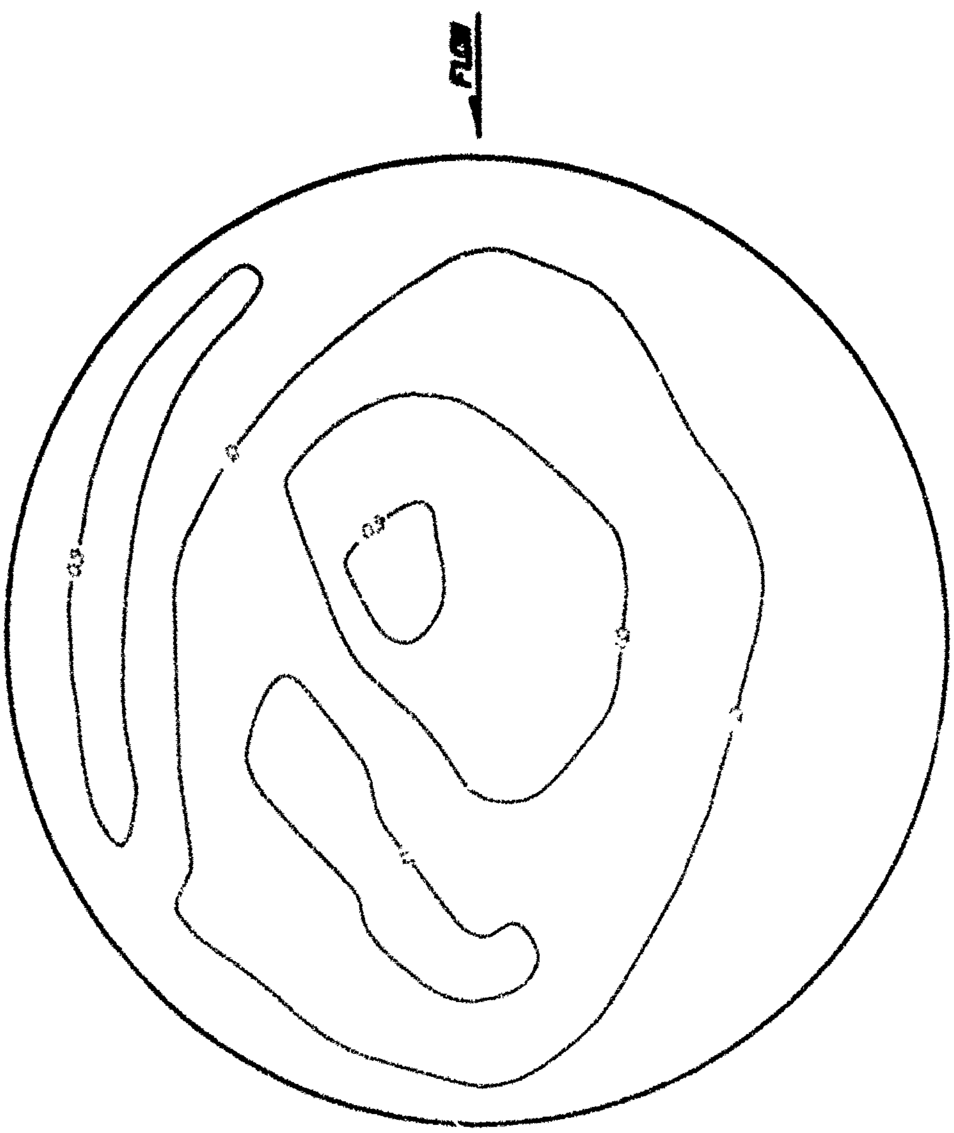


TEST CONDITIONS
WATER SURFACE EL [illegible]
DISCHARGE [illegible]

$R_V = \frac{V_M}{V_C}$ = MEASURED AVERAGE AXIAL VELOCITY / COMPUTED AVERAGE AXIAL VELOCITY

$V_C = \frac{Q}{A}$ = DISCHARGE / AREA OF PUMP COLUMN CROSS SECTION

LINES OF EQUAL VELOCITY RATIOS
TYPE 16 DESIGN SUMP
AVERAGE VALUES R_V



TEST CONDITIONS

WATER SURFACE EL

DISCHARGE

MEASURED AVERAGE AXIAL VELOCITY

COMPUTED AVERAGE AXIAL VELOCITY

DISCHARGE

AREA OF PUMP COLUMN CROSS SECTION

LINES OF EQUAL VELOCITY RATIOS
TYPE 16 DESIGN SUMP
25 PERCENT TRASHRACK BLOCKAGE
AVERAGE VALUES R_V